DOCUMENT RESUME

ED 327 390 SE 051 837

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TITLE	The Teaching and Learning of Biology in the United States. Second IEA Science Study (SISS)-United States.
INSTITUTION	Columbia Univ., New York, N.Y. Teachers College.; International Association for the Evaluation of Educational Achievement, New York, NY.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	89
CONTRACT	NSF-SPA-847032
NOTE	155p.
PUB TYPE	Information Analyses (070) -- Tests/Evaluation Instruments (160) -- Reports - Research/Technical (143) --
EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	Biological Sciences; *Biology; *Comparative Education; Mathematics Tests; *Science Curriculum; Science Education; *Science Tests; *Scientific Literacy; Secondary Education; *Secondary School Science; Teaching Methods
IDENTIFIERS	*Second International Science Study

ABSTRACT

Some understanding of biology is needed for the success of individuals in modern societies. This monograph is a report of an assessment of educational achievement by a sample of secondary school biology students in the United States within the context of current knowledge of teaching and learning strategies, the role of biological literacy in modern schooling, and some implications of the test results for improvement of modern biology education. The central focus of the report is a description of the test results for the first and second year biology students who participated in the Second International Science Study (SISS) sponsored by the International Association for the Evaluation of Educational Achievement (IEA). Discussions center on: (1) an "Introduction to biology education in modern society and the concept of biological literacy; (2) "Biological Curricula," which includes historical perspective, the Biological Sciences Curriculum Study, and biology textbook content; (3) "Studies on Biology Achievement"; (4) "The SISS: Rationale, Methodology, Instruments"; (5) "Results of the Second IEA Study: Biology Achievement"; and (6) "Conclusions," which contains findings and implications for biology curricula and learning. Each chapter includes a list of references. Appended are the first year and advanced biology content tests, student questionnaire items and responses, and mathematics tests given to the first year and advanced biology students. (CW)

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THE TEACHING AND LEARNING OF BIOLOGY

IN THE UNITED STATES

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And

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A Monograph of
The International Association for the Evaluation of Educational Achievement [IEA]

Second IEA Science Study
[SISS]
UNITED STATES
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SE051837

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This material is based upon work supported by the United States National Science Foundation under Grant No. SPA 847032. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the United States National Science Foundation.

Foreword

An important monograph. The results of the Second International Science Study are discussed within the context of literacy in the biological sciences, curriculum development in biology, and biological science education research. There is a discussion of the nature of the biological sciences education needed by everyone in modern societies--biological sciences literacy. There is also a historical view of the development of biological sciences curricula and an analysis of relevant biological sciences education research. Of special interest to teachers of biology, science supervisors, and biological sciences curriculum developers are sets of biological sciences instruments and the item statistics. These are now available in this monograph for use in improving instruction in biology in our schools.

Some understanding of biology is needed for the success of individuals in our modern societies. But, what biological understandings and skills are needed? A two-dimensional model of biological literacy is proposed. This two-dimensional framework for biological literacy is used in the search for the optimal organization of biological curricula and for the most effective modes of instruction.

An historical perspective on the development of biological sciences curricula is offered. It is well to be aware of what has gone before. Certainly, modern biology curricula continue to be influenced by the biology texts and other curriculum materials developed under the auspices of the Biological Sciences Curriculum Study (BSCS). Such biological materials and related studies provide the framework with which the results of other studies, such as the Second International Science Study, can be interpreted..

There also has been considerable research into the factors that affect achievement. For example, Professor Anderson's studies of neurocognitive models of information processing and knowledge acquisition are among the kinds of studies that should influence future developments in biological sciences curricula. Out of these studies have come models of instruction that are useful in improving effectivness. Some of these models are described in this monograph.

In the study of achievement in biology in 1986, two populations were tested. The Biology I Test was administered to first year biology students usually in the tenth grade. The Biology II Test was administered to students who would have two years of biology and were usually in the twelfth grade. The items in the instruments have been classified, and these classifications have been used in the analyses. For example, It appears that the mathematics skills assessed by the Mathematics Test contribute some of the variance in the biology test scores. In addition to the tests, students responded to questionnaires, opinionnaires, a word knowledge test, and a mathematics test. The analyses of the data collected helps to identify the strengths and weaknesses of our biology education programs and illuminates some of the problems we face in biology instruction.

Copies of all the instruments used and the item statistics are appended in this monograph. You can use these carefully prepared instruments in your testing and biology curriculum development programs. You may wish to find out the kinds of questions on which your students do best or the items with which they have the greatest difficulty. Also, you can compare your students' scores with those from the national samples.

Professor Anderson is a Professor of Natural Sciences at Teachers College, Columbia University. He is a leader in science education instruction and research. He is also a Senior Research Scientist at the Biology Laboratories of the Lamont-Doherty Observatory of Columbia University.

Willard J. Jacobson
National Research Coordinator
Second International Science Study

Preface

This monograph is a report of an assessment of educational achievement by a sample of secondary school biology students in the United States of America. The study was done under the auspices of the Second International Science Study (SISS) sponsored by the International Association for the Evaluation of Educational Achievement (IEA), and funded in part by the United States National Science Foundation. The IEA is a federation of international scholars with multi-national interests in educational achievement. Founded in 1967, the IEA has sponsored several international assessment studies over the last two decades and their role in the study reported here is described more fully in Chapter Four. We are pleased to also acknowledge the support of the National Science Teachers Association, Washington, D. C., the Spencer Foundation, Union Carbide Corp., and Teachers College-Columbia University.

The central focus of this report is a description of the test results for first year and second year biology students who participated in the study. These two samples (especially the first year biology sample), prepared by the Research Triangle Institute (Research Triangle Park, North Carolina) are reported to be highly representative of the Nation's schools and their biology students. Within the major focus of this report, the findings have been embedded in a context of "The Teaching and Learning of Biology in Secondary Schools" as a theoretical rationale for the report. This context is based on some current knowledge of teaching and learning strategies and the role of biological literacy in modern society . It is a means of organizing the findings and where possible presenting some practical conclusions. The report is not intended to be a thorough review of current learning theory and its implications for biology teaching, but hopefully will provide some background insight into the development of modern secondary school biological curricula, the role of biological literacy in modern schooling, and some implications of the test results for improvement of modern biological education. The background literature for this report has been highly selected, largely based on a criterion of a need for parsimony and the relevance of the research to the kinds of learning assessed by the SISS test items. Therefore, the background literature survey may not be fully representative of the scope of current theory and practical wisdom in the field of biological education. It is clear that not all of the major current research findings can be represented as background data in a report of this limited scope. Thus, lack of citation of a research report does not imply lack of worth.

I am deeply indebted to the staff of the SISS who have generously provided background information about the SISS and its data set. Willard J. Jacobson (National Research Coordinator, U. S. A.) and Rodney L. Doran (Associate National Research Coordinator) have been particularly helpful in providing insights into the theoretical and philosophical rationale for the SISS effort on a broad scale. I also thank Mark Rinkerman (Data Manager) for his technical advice and statistical expertise in data reduction and analysis. Ms. Jan Owen (Administrative Assistant) has been very helpful in guiding me through the maze of technical information associated with the SISS To the members of the National Committee who have given advice in preparation of this document, I express my sincere appreciation. Any omissions or inaccuracies, however, are the responsibility of the author. The views and opinions expressed here are not necessarily those of the sponsoring organization nor the funding agencies, and should not be assumed to be authorized by any of the supporting agencies including the United States National Science Foundation. In all, I trust that this report will stimulate critical dialogue and hopefully provide some insight for improvement of biological education in the United States and, where appropriate, internationally. I am pleased to have contributed to the endeavor of the SISS and to the significant work that our secondary school educators perform in the enhancement of human lives and the creation of a better society.

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Chapter One
INTRODUCTION

Biological Education in Modern Society

The opportunity for a free, comprehensive and high quality education for all is an ideal deeply rooted in American culture. This ideal, though not universally realized, has been invoked in widely divergent socio-political contexts and remains a consistent theme among educational reformers[1]. Throughout much of this century, secondary schooling has been the highest level of formal and comprehensive education for many of our citizens, and has become increasingly a key transition stage in the quest for a higher education for all who are intellectually capable. It is clear that the quality and intellectual depth of secondary education, including the development of adequate knowledge structures and cognitive skills, often makes the difference between success or failure in the transition toward a successful and complete higher education[2].

A comprehensive and sophisticated understanding of science has increasingly become a significant hallmark of an educated individual in the twentieth century. Science is not only a tool of modern society; it has occasioned, if not stimulated, some of the most profound philosophical reflections about our identity as human beings and as a social order. The products of our scientific thinking, ironically have not only relieved us of many technical and ideological burdens, but have also occasioned new dilemmas technologically and ethically[3]. The opportunities for progress through enlightened and benevolent application of scientific insights have been tempered by the potentially destructive misuse of our newly gained control of natural phenomena. This dilemma is not only limited to the oft cited potential dangers of misused atomic energy, but also extends to other ethical issues such as: 1. what part and how much of the natural environment will be exploited for immediate human progress, 2. to what extent will increasing proportions of the gross national product be allocated to technological and military applications of scientific knowledge versus improvement of individual quality of life, and 3. to what degree should humanity take control of the fundamental hereditary apparatus of life toward remaking species including our own. 4. As a corollary, if the human genome is fully mapped who will receive this information? What are the possible consequences for the spirit of free scientific inquiry if information in withheld, and conversely how will this fundamental information regarding human welfare be protected if at all from exploitation? If we can fully prescribe the genome of a human life, who shall decide the composition of this fundamental hereditary code especially if it impinges on the neuro-cognitive capacities of the "genetically engineered" human individual. Science, thus is not only part of a liberal education, but increasingly is the context for our definition of humanity, and the refinement of our social ethos.

Many of the profound questions confronting modern society emerge increasingly from applications of research in the biological sciences. Biomedical questions, more than in the past, literally involve decisions of human life or death. These include modern techniques for the proscription of life or its prolongation, the amelioration of malaise and enhancement of life through allocation of limited biomedical resources, and the possible control or prevention of congenital diseases and other in-born errors of metabolism through application of genetic engineering. Many of the ethical criteria for these decisions, and questions of allocation of public funds, may be referred to our citizenry or their legal representatives. This implies increasing expertise, or at least biological scientific literacy, by a broader base of liberally-educated people. The expanding market for specialists in wide ranging fields spun off from biological scientific research, and the likely increase in expanded opportunities in service professions based on biological technology ranging from biomedical counselling to advisers in agricultural and domestic resource applications, portend a growing demand for biologically well-informed professionals.

In a democratic society, it is becoming increasingly clear that narrowly educated specialists cannot make, and probably should not make, many of the moral and practical decisions that affect the quality of our lives. Many of these questions center in environmental, biomedical, and energy resource utilization issues. These questions increasingly expand to include truly universal issues such as the expansion of human life into extra-terrestrial space. Who shall go, how many individuals, at what expense to the population left behind, or at what potential corporate gain to society relative to immediate cost for its individual members? What shall be the biological and social cultural heritage carried from our terrestrial experience into this new world? If we take other living organisms with us into these new environments, what genetic heritage (represented by selected species or their genetic libraries) and ecological systems will be most relevant and ethically sound given the possible uncertainties of these newly inhabited worlds. Many of these decisions require a scientific literacy that extends beyond specialist knowledge. They require a systemic view of the interrelationships of principles from the physical, biological, economic and socio-psychological sciences. The multivariate consequences of alterations in a seemingly unitary variable in our physico-bio-social environment often go overlooked by focal specialists in a field, and most probably will be overlooked by narrowly educated citizens who are incapable of understanding the web of interactions that maintain a balanced and productive environment.

Biological Literacy

A biologically well-educated and literate citizenry becomes of increasing significance as the complexity of science-based decision-making increases. Little consensus exists as to a definition of scientific literacy and in some cases the concept is discussed from multidiscipinary perspectives without a clear coherent conceptual base. Some interdisciplinary viewpoints by leading scholars have been presented in a special volume of *Daedalus*[4]. These articles include analyses of 1. scientific literacy from an international economic perspective[5], 2. its relationship to democratic theory[6], 3. its role as a framework for decision-makers[7], and 4. implications for improvement of science education[8].

Definition of Biological Literacy.

A definition of biological literacy, as with the broader definition of scientific literacy, is not easily reduced to a unitary description. Indeed, it is likely that such literacy is better defined as a continuum of cognitive states mapped into at least a two-dimensional field (Fig. 1.1). This conception is presented here as an ideational framework for a subsequent more generalized discussion of modern biology curriculum development in subsequent chapters.

The two-dimensional model is bounded by two axes forming continua of information processing abilities. The coordinates of any two points on these axes defines a point in the plane of the figure representing the combined contribution of the characteristics of the points on the two axes. Four quadrants have been selected in the plane of Fig. 1.1 to illustrate four major combinations of coordinate points. These descriptors are derived from a range of points on each axis bounded by the dashed lines. A more detailed description of each point on the dimensions of Axes One and Two is presented in Tables 1.1 and 1.2 respectively. The major characteristics of each dimension are described in the following paragraphs.

The coordinates on Axis One are: 1A. competency in comprehending the appropriate field of science represented by the scientific meanings in a communication, but not necessarily including an ability to make interpretations or explanations of the phenomenon. This is the lowest level of semantic competency and represents an awareness of the appropriate context for the scientific meanings; 1B. interpretive competencies, including the ability to analyze the information given and interrelate it to form a new expression of meanings; 1C. explanatory competencies, including the ability to inform others of the scientific meanings; skill in interrelating the information internal to the communication, coherently organizing it into a clear exposition, and communicating it cogently to others; 1D.

extrapolation and implication competencies in extending the information given to include likely consequences of the phenomenon discussed, the logical, semantic, and cultural origins of our interpretations of the phenomena, and the likely future scenarios that may emerge; 1E. application competencies, including skill in determining the appropriate contexts for applying the information or scientific methodology in new settings, knowledge of the likely boundary conditions that constrain applications, and the necessary standards needed to evaluate the efficacy of the application(s); 1F. Competency in creating new or innovative information or methodologies based on the scientific meanings communicated, including expert knowledge about a field and the boundary conditions and rules of logic that pertain to constructing novel interpretations in the field and building theory.

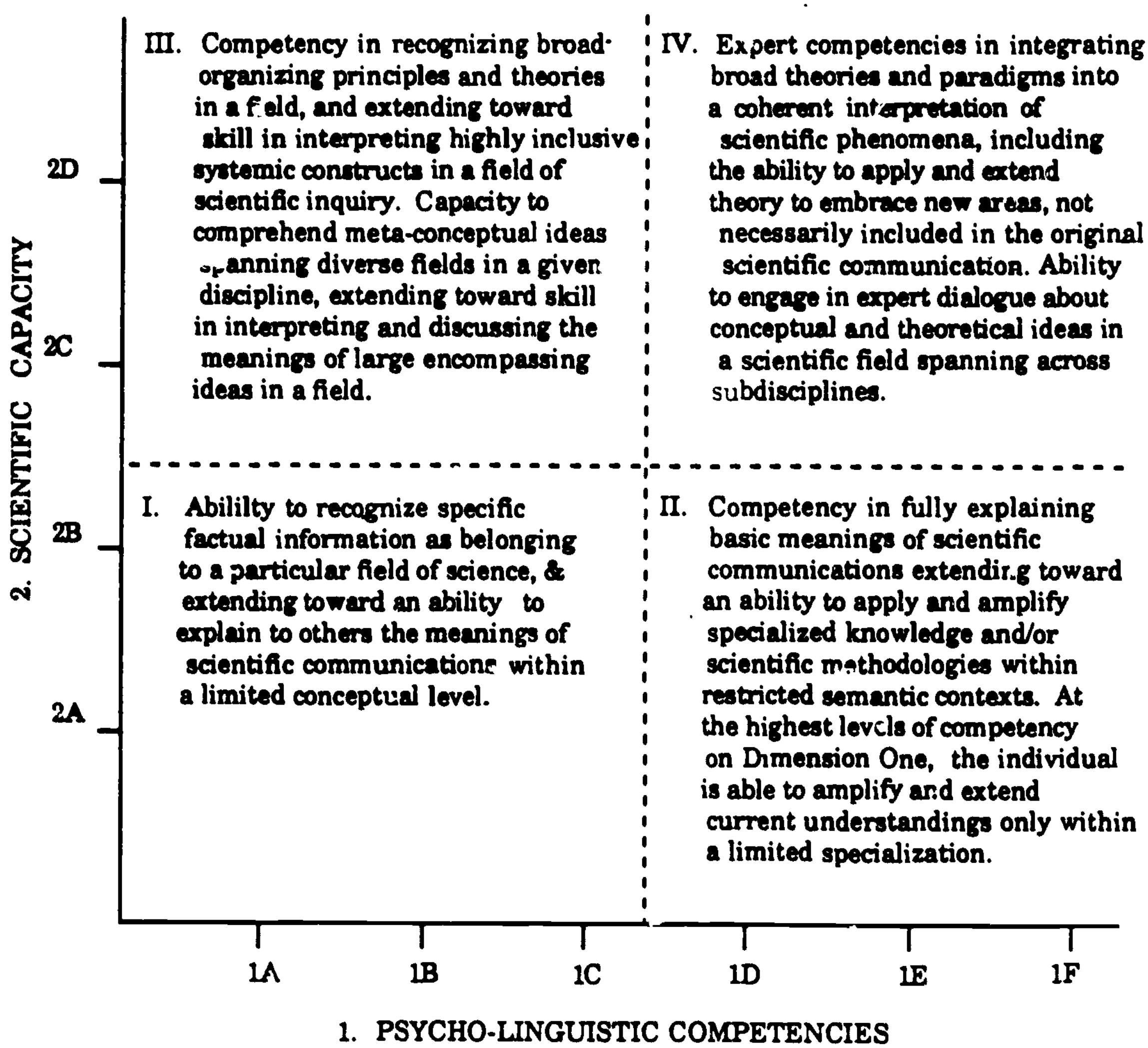

Figure 1.1 Two-Dimensional Model of Scientific Literacy (See Tables 1.1 and 1.2).

Table 1.1 Scientific Literacy Competencies: Dimension One

1A Contextual Comprehension

The ability to recognize that information is relevant to a particular field of science, as for example in biology to comprehend that the meanings pertain to molecular biology, or human biology, etc.; and to make a general judgement as to whether the information is very fundamental to the field or more advanced.

1B Interpretation

To be able to analyze and interrelate information in a scientific communication and to render it in a new form, as for example to be able to understand that elevation of temperature in a river by industrial discharge and the low yield of fish in a nearby spawning pool may be interrelated and to be able to make some explanation for the effects.

1C Communication

This level of literacy goes beyond the explanatory competencies cited in 1B to include the ability to synthesize the information into a coherent and logical form suitable for communication to others. This requires that the individual be able to reflect upon the organization of the information and make critical judgements about ordering, interrelating, and establishing meaningful contexts for the information so as to communicate it to others.

1D Inference and Extrapolation

This stage goes beyond the ability to reorganize and communicate information meaningfully to others, and includes the competency of discovering inferences within, and implications of, the communicated information. For example, reports of increased toxins in major rivers extending to estuaries, may indicate that the oceans are being increasingly polluted. The consequences of this change could mean lowered productivity including decreased fish production as well as potential climatic changes. Further skills in extrapolation are included here. For example, to recognize that a moderate rise in global mean temperature could have marked effects on agricultural productivity.

1E Application and Standardization

This competency requires the ability to transform information to make it applicable in varied contexts, including the ability to make judgements about which contexts are appropriate. The necessary criteria to be met for valid application of scientific methods and for improving models and theories are also included here. The individual should be able to state the boundary conditions that establish reasonable domains for use of scientific information or application of scientific methods. For example, analysis of particles in the nanometer range is most likely done by high resolution electron microscopy or ultramicroscopy, not by conventional light microscopy. Likewise, judgements about the transferability of biomedical experimental data from animals to humans may involve questions of the similarity in physiological responses of the two species, and differences in tolerances to doses relative to species life-span differences, etc.

1F Elaboration

This is the highest level of literacy including the ability to create new and novel explanations based on scientific information, contribute to elaboration of methodology or theory in the field, and exhibit expert knowledge about the field and its rules for inquiry. The individual should be able to engage in constructive expert dialogue. For example, an individual who is presented with a problem of how to overcome resistance to a medicant, should be able to draw on advanced biomedical research data, discuss the requirements for the innovation and produce scientifically verifiable suggestions for ameliorating the problem.

Axis Two is divided into four major coordinates for convenience. As with Axis One, it represents a continuum of abilities of increasing inclusiveness. Here, the emphasis is on the scientific content and the individual's cognitive capacity to comprehend models of experience that are increasingly theoretical or systemic in their comprehensiveness. The coordinates are defined as follows: 2A. specialized or unitary factual content, perhaps related to only a narrowly defined segment of scientific phenomenology; 2B. conceptual information that provides broad categorizations of phenomena including wide breadth and abstractness of defining attributes for the concept. 2C. Inter-conceptual information that permits meta-cognition among diverse constructs within a discipline or among disciplines, including rules for transforming information from one context to another and making logical transits across defining states of phenomena within and among disciplines. 2D. Theoretical and systemic information of a broad and comprehensive kind permitting interrelation of constructs among disciplines including relevant criteria for making evaluations of the scientific accuracy of knowledge claims, comprehension of the historical antecedents for current constructs, and criteria for evaluating the heuristic merits of proposed innovations in the field.

Increasing sophistication in interpreting and extending scientific knowledge of ever greater inclusiveness is categorically mapped as the four quadrants (I to IV) within the two dimensional field of the model. This compartmentation is intended only as a convenience in displaying the major characteristics of some domains within the model, and is not an inclusive definition of total domains that can be generated by finer analysis of fields generated by coordinates on the axes. In general, the trend is from fundamental awareness of issues and meanings in a restricted context toward a comprehensive and systemic, theoretical interpretation of phenomena with expert dialogue capacity.

Hence, at the highest levels of scientific literacy, we would expect the individual to be not only a consumer of information, but capable of discussing concepts and issues in a coherent and authoritative manner. This is not used in the sense of authority based on dogma. By authoritative, I mean an understanding of scientific issues broadly conceived and based in scientific evidence. On the continuum of Axis One, this kind of authoritative understanding begins to emerge at about the mid-point (1C) where the individual is capable of using explanatory competencies to inform others of the meaning of scientific communications and phenomena. On Axis Two, transition into this authoritative capacity to deal with comprehensive scientific issues occurs about the level 2B where the individual possesses broad conceptual understandings in a field of science.

Table 1.2. Scientific literacy capacities. Dimension Two

2A Specialized-Factual Information

This is the lowest level of information inclusiveness on the capacity dimension and represents understandings that are limited to specific facts, and isolated factual information within a specialized field of science. For example, an individual who exhibits minimal capacity on this dimension, knows how to define species as a group of organisms that can interbreed, or knows also that species make up populations. It does not include broad conceptual knowledge that integrates information into abstract categories.

2B Conceptual Information

The capacity to use inclusive categorizations of information marks this level. For example, an individual at this level should be able to recognize broader aspects of the meanings of species such as: a species constitutes a genetic as well as morphological and reproductive unit in a population and it is not a fixed entity, but is under the influence of environmental pressures and constraints that may induce changes with time, including fundamental changes in the genetic constitution of the individuals in the species category.

2C Inter-Conceptual Information

This capacity is an extension of level 2B and includes the ability to make multiple inter-relationships among concepts, thus serving metacognition by synthesizing information, and giving meaning to information, among previously separate conceptual categories. For example, interpretations of the action of viruses in causing transformation of cell activities should be relatable to the transforming principle of bacterial DNA that accounts for changes in genetic composition of bacteria grown together. And, based on this knowledge, possible explanations for viral-induced changes in cells leading to malignancy may be suggested.

2D Systemic-Theoretical Information

This is a capacity to see phenomena in a systems-viewpoint. To understand that there are broad generalizations and explanatory principles that can account for our interpretations of organized form and orderly relationships among natural events. This also requires an understanding of the principle that a system is a set of interrelated units, mutually influencing one another in an orderly and predictable way, that can be explained by one or more generalized rules. It also assumes knowledge of a highly inclusive and abstract kind providing sophisticated skill in comprehending and subsuming new information within theoretical constructs in memory. For example at this level, an individual may utilize the theory of evolution to explain diversity of life, adaptations that permit introduction of new species into a geographical area or prevent their assimilation. This knowledge may generalize to include understanding the phylogenetic historical origins of inborn errors, other heritable disease, the likely reasons for recent environmental changes inducing maladaptations in one species versus another, etc.

The issue of scientific literacy, especially as applied to biology, is further complicated by the medium of communication and the context for the meanings being conveyed. With respect to medium, biological information is often conveyed visually in addition to written and oral modes.

Visual information processing includes skill in interpreting a range of data sources spanning atomic or molecuiar evidence (e.g. electron micrographs and graphs of action spectra), cellular and tissue data (as in light micrographs and cytochemical visual evidence), and visual records of ecological phenomena and animal behavior. Among these various modes of information presentation, there is also the issue of context Can the individual properly assign the information to a relevant biological context and make critical judgements about its scientific and practical merits? In contrast to some of the physical sciences where the field is more hierarchically ordered and domains of investigation are more clearly delineated, biology involves a wide range of experimental and conceptual domains spanning molecular biology to global ecology. The significance of phenomena from a perspective of worth in theory building and heuristics, or practical and technological merit, varies substantially among the several sub-disciplines. For example, the issue of whether or not we should permit gene splicing in human tissue cultures may have little bearing on global ecology, but the same issue raised in the context of large scale programs to genetically alter rapidly growing plants in the natural environment may have profound global ecological consequences. Hence, the ability to make fine judgements of the contextual significance of biological information, and the ability to properly categorize a scientific issue within a domain of biology becomes of increasing importance in defining biological literacy. Additional refinements in defining literacy also include the level of sophistication in understanding scientific communications of varying technical complexity. For instance, an ability to read and interpret "typical secondary school textbook narrative" is quite different from understanding a technical scientific report, especially if the latter is intended for a specialist audience. Along this dimension, several guide marks can be identified. At a minimal level, the literate individual may be able to at least extract the general theme or "jist" of the argument in these more sophisticated documents. With increasing competency, however, they should be able to comprehend the major conceptual issues, identify underlying inferences, deduce implications, and evaluate the scientific merit of the information. The extent to which an individual understands phenomena within a perspective of problem solving potentials and strategies versus merely passively accepting information is another dimension that should be considered in designing relevant curriculum experiences and evaluating progress in development of scientific literacy[9,10].

Clearly, not everyone can be equally literate in all aspects of science, and indeed there appears to be wide diversity in adult understanding of basic scientific ideas and methodology[11]. Among adults in 1979 who completed a high school degree, only 5% were judged to understand "the scientific approach", and with respect to scientific concepts the percentage understanding major modern ideas ranged from 15% for the concept of DNA to 47% for radiation[12]. In the same report, the percentage of adults who completed high school and who were judged to be overall scientifically literate was a meager 2%; while 22% of those who completed a college baccalaureate degree were categorized as scientifically literate. As with any research investigation, the foregoing results must be evaluated in relation to the criteria for literacy employed by the researchers and relative to the item difficulty in their instruments. However, assuming internal consistency, it is clear that those who are capable of achieving a college degree show considerable, though not remarkable, gains in scientific literacy. Given the diversity of modern scientific conceptions and the range of potential topics that could be included in modern biology courses, it is all the more important that curricular decision-making include some informed analysis of the level of scientific literacy to be achieved. This may include adequate attention to the aesthetic understandings that characterize a minimally biologically literate member of society. The role of affective as well as cognitive outcomes in biological education remain a significant part of modern schooling[13]. In large measure, a sound and systematic understanding of biological phenomena has been traditionally, and continues to be, based in an aesthetic understanding of our position as human-beings amidst the spectrum of life forms dwelling on our planet. The fundamental understanding of the numerous adaptations of life in relation to an ever changing environment and the clearly remarkable way living systems maintain a balanced and continuous state of life in the midst of change, including that of our own human system, remains an aesthetic understanding that all educated persons have a right to claim. In this sense, as much as in the practical necessities cited before, a comprehensive and integrated biological education remains a major objective of modern education. The opportunities moreover to gain insights into scientific reasoning at varying levels of abstraction, when carefully sequenced to complement the developmental level of the learner, are particularly potentiated by the wide range of inquiry skills and varied levels of conceptual abstractions presented in the biological sciences[14]. Some major new designs in science curricula based on broad organizing principles and integrated science content are welcome innovations[e.g.15,16]. The search for optimal curriculum organization and most efficient strategies of instruction to best serve the diverse clientele of American secondary schools remains one of the most significant endeavors of our modern society.

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Chapter Two
BIOLOGY CURRICULA

Historical Perspective

The progress of biological thought from dependence on the dogmatic authority of herbalists to the theory-based, open-inquiry paradigms of modern science has been accompanied by a slow but steady progress in redefining processes of biological education. The earliest methodology centered on reproducing the drawings and concepts portrayed in the herbals or their many, and sometimes inaccurate, reproductions. The issue of whether the meanings were consistent with one's own empirical observations of the natural world seemed to be irrelevant in this authority-based paradigm. As biology emerged from the dominance of Natural Philosophy, largely based on religious dogma, increasing emphasis was placed on systematic and formal empirical data gathering. With increasing maturation of the field, these data were compiled toward testing of biological theories rather than confirming ad hoc explanations or those based on superstition. Concurrently, biological teaching methods gradually progressed from reproducing information in hand-drawn figures toward greater focus on individual observation. Ultimately, methodologies progressed toward increasing emphasis on individual investigation and experimental analysis of biological phenomena. This philosophical ideal reached a high-point in the curricular reforms that emerged following the launching of the first man-made terrestrial satellite in 1952 by scientists in the Soviet Union. This epoch-making event shattered American complacency about our scientific superiority and occasioned massive efforts to upgrade American science at all levels including secondary education.

The broad history of secondary school biological education from 1890 up to the mid-twentieth century has been comprehensively reviewed by Hurd[1]. He divided his historical account into seven periods, and analyzed the changing philosophy and practices of secondary school biology education in relation to prevailing national needs, contemporary ideas about the role of education in human intellectual development, and the current theory and knowledge structures in the biological sciences. During the period of 1890-1900, increasing numbers of students were entering American secondary schools and colleges. The advance of industrialization, and increasing needs for technically educated persons to fill the expanding skilled and professional positions in business and industry, led to a large increase in secondary school students who saw a high school education as the final stage in preparation for a life career. The proportion of individuals who continued on to college declined. Simultaneously, the colleges became increasingly concerned about the lack of uniformity in quality and content of pre-college science education. These factors amidst other major social transformations of the period led to a period of serious examination of the role of secondary school biological education. Recommendations for curriculum reform as summarized by Hurd[2], included:

1. Continuous offering of biological science from the first grade through high school.
2. A required course in biological science at the tenth grade level.
3. At least one year of biology for college entrance.
4. Increased uniformity of content in secondary school biology.
5. Introduction of a laboratory experience in secondary school biology.
6. Increased emphasis on the broader principles of the discipline rather than memorization of isolated facts.
7. All young people should be instructed in hygiene and physiology before completing high school.

The emergence of laboratory-based biology instruction and emphasis on morphology rather than natural history established the foundations for modern approaches to investigative biology teaching as opposed to memorization and recitation.

During the period of 1900-1910, earnest efforts were made to develop a biology curriculum that was more appropriate to the diverse intellectual capacities and career interests of the students while building on the foundations prepared in the foregoing decade. The general biology curriculum emerged as a synthesis of major ideas in biology as opposed to teaching specialized courses in botany, general zoology, or physiology as prevailed in previous decades. The new synthesis was not without controversy. Some hailed it as a means of forcing teachers to focus on the important ideas about living things. Others decried it as leading to imperfect knowledge in a far too diluted curriculum to permit systematic accumulation of information about a given field. This period also was accompanied by a new perspective on the rationale for science instruction. The idea of "mental discipline" was gradually giving way to a new differentiated psychology, it was no longer assumed that intellectual demand of any kind was suitable for generalized mental development. Consequently, the unique contributions that science and biological education in particular could make in improving human intellectual development began to be seriously considered.

In the ensuing decade (1910-1920) the critical role of science in advancing technology and industrialization in America led to more intensive refinements in the sequential organization of science education in American schools. General science was introduced in the ninth grade, and the role of the laboratory in secondary biological education came under increasing scrutiny. Some of the criticisms and recommendations reflect a theme that was to appear with greater vigor in the mid-twentieth century. For example, the following recommendations were made for improvement of laboratory teaching[3]:

"1. Too many experiments merely check generalizations the student already perceives and repeat work given in the text.

2. The data collected are an end in themselves and have no further use.

3. Experiments are minutely quantitative and call for refinements beyond the understanding of secondary school pupils.

4. Laboratory and classroom are separated not only physically but intellectually.

5. Notebook making and notebook records serve no real purpose."

In general, the period was marked by increasing emphasis on science as a way of thought, more active involvement of the learner, and greater emphasis on projects, problem solving, and use of questions in teaching to elicit student scientific reasoning.

During the following decade in 1920-1930, there was a refinement of the trends toward greater emphasis on scientific problem-solving and the "humanization" of secondary biology instruction. This included adequate attention to the elements of scientific methods and scientific attitudes, and the impact of science on society. If this decade was characterized by steady forward movement toward reform of secondary biological education, the following period of 1930 to 1940 was more marked by serious questioning of both the merits of and rationale for secondary school biological instruction. The occurrence of the depression, and as is usually the case during times of social upheaval the critical appraisal of social ideals and national institutions, led to a reappraisal of the role of secondary science education curricula. The increasing products of technology found in the home, industry and agriculture increased general public awareness of science as an important component of modern life. However, the stringent economic crisis also occasioned calls to re-evaluate the merits of continuing science instruction. The very continuance of secondary school science was debated amidst concern about its economic costs, and relative to changing educational philosophy. Increased emphasis was placed on learning biological principles and ordering specific factual content to build toward conceptual understanding as a means of fostering problem solving. In this view, curriculum content was best defined in the context of principles and generalizations leading to more adaptable curricula and greater consistency with learning theory. Psychological principles of learning became more significant as a guide to curriculum design. The onset of World War II and the emergence of the "Atomic Age" during the period of 1940 to 1950 placed a new emphasis on science education as an aid to career development and as a practical tool in maintaining national industrial and military strength. Much emphasis was given to applied aspects of biology including hygiene, guiding students into joining the ranks of pure and applied scientists, and preparing citizens to be more intelligent and efficient consumers. Less emphasis was given to informed curriculum design based on learning theory and more focus was placed on philosophy of social reform and the role of science as a tool of society. During this period, however, the general biology course continued to gain enrollment. Hurd[4] reports that by 1950 nearly all of the high schools in America offered general biology and 21.7% of all high school students were enrolled in a biology class. The increasing uncertainty about the role of secondary biology education in meeting the technological and manpower needs of the nation reached a zenith during the period of 1950-1960. The increasing awareness in America that our technological leadership and military strength might not be keeping pace with international progress, was jolted into a national sense of crisis with the successful launch of the Soviet terrestrial satellite. This sheer fact of technological achievement by a foreign nation, probably more than any other philosophical rationale for education reform, led to a massive reassessment of American science education at all levels. Within this melange of demands for technological and educational reform, secondary school science curricula came under critical scrutiny especially toward making them scientifically sound and educationally effective toward ameliorating the perceived erosion of American scientific leadership.

The Biological Sciences Curriculum Study

The thrust in the biological sciences was vested in the Biological Sciences Curriculum Study Committee at Boulder Colorado. This Committee, comprising biologists, scientific philosophers, and educators at the secondary school and college level, commenced its work in 1959 and by the early sixties had produced three major, newly conceived textbooks in biology. Each of the texts emphasized a different aspect of biology and were identified by code colors. The "Blue Version" emphasized molecular biology, physiology and evolution. Subsequently, it was published with the title *Biological Science: Molecules to Man* [5]. The "Yellow Version" focused on genetics, evolution and broad aspects of general biological education. It was titled *Biological Science: An Inquiry Into Life* [6]. A "Green Version" emphasized ecology, and was published under the title *Biological Science: An Ecological Approach* [7].

All of the texts were organized around major themes representing current biological thought, and particularly embedded in the context of scientific enquiry. The concept of "scientific enquiry" was articulated by Schwab[8], a philosopher of science, who divided scientific epistemology into content and syntax much as a linguist divides language into vocabulary and syntax. The syntax of science was viewed as the multi-faceted modes of examining natural phenomena employed by scientists. Schwab, among others, clarified that scientific enquiry is not reducible to a set of rules as often presented in texts under the rubric of "The Scientific Method." Rather, enquiry entailed a fluid and dynamic interaction of the investigator with the opportunities and constraints provided by the context of the enquiry including: 1. the qualities of the natural phenomena being investigated, 2. current tools of science, and 3. the cognitive skills and knowledge base at that point in history. Thus, although many of the steps rigidly codified in the former description of scientific method were viewed as valid, the key focus was on creativity and novel ways of employing experimental design criteria in addressing scientific research questions. Consequently, the texts offered less specific step-wise instructions on scientific enquiry, but provided examples of scientific discoveries and processes usually embedded in an historical context. Moreover, Schwab decried the format of contemporary texts that in his view presented scientific information as a "rhetoric of conclusions." The content of science was rendered as a litany of conclusive statements that approximated a list of unalterable truths. This in Schwab's view, and apparently also that of the BSCS Committee, implied that science was unchanging and engendered a belief system that science is a body of truth and not a dynamic evolving system of knowledge and methods of investigation. To ameliorate this oversight, the BSCS text writers set forth to embed all content in an enquiry context while stabilizing the information within a matrix of content themes that were intended to provide continuity of ideas.

In addition to the Enquiry theme, the remaining "content-based" themes and sub-themes (indicated by indentation) included[9]:

1. Change of living things through time exemplified by evolution
    2. Diversity of type and unity of pattern in living things - an emphasis on variations among taxa unified around common patterns of biological function.
    3. The genetic continuity of life - focusing on the mode of hereditary transmission and its variation over geological time resulting from natural selection.
4. The complementarity of organism and environment - the mutual interaction of abiotic and biotic factors in the environment with developmental and behavioral responses of the individual organism.
    5. The biological roots of behavior - relating organismic and group behavior to genetic and physiological variables.

6. The complementarity of structure and function - the mutual interaction of form and dynamics in biological systems with an emphasis on the ways structure and function can be deduced by examination of living systems.
7. Regulation and homeostasis: preservation of life in the face of change - a systems view of life based on feedback mechanisms and regulatory functions such as the role of growth substances and hormones.
8. The history of biological conceptions - an historico-philosophical analysis of the development of biology as a field of enquiry.

These themes were further amplified within a content hierarchy representing increasing inclusiveness of biological phenomena:

1. Molecular - the atomic, molecular, and physico-chemical bases of biological phenomena.
2. Cellular - the form and function of cells as the fundamental unit of living things.
3. Tissue - the structure and function of groups of cells having a common embryological origin and serving a specific set of biological functions.
4. Organ - the organization and role of organs as function-specific groups of tissues.
5. Systems - the coordinated and mutually interactive roles of organs in maintaining the stable life processes of a healthy organism.
6. Organism - the individual of a species as a biological structural functional unit taken as an entity or as a component within a broader ecological system.
7. Population - all individuals of a given species within a defined environmental domain.
8. Communities - interacting groups of species (populations) living within a given environmental habitat and forming a recognizable unit of ecological structure and function.
9. Ecosystems - large-scale environmental systems consisting of communities adapted to a particular abiotic environment.
10. Biomes - major climatic and geographic regions of the world characterized by some uniformity in ecosystem composition; hence, large scale habitats and their life forms.

Whether these themes were developed sufficiently explicitly in the texts to serve as clear organizing perspectives for most secondary school students remains to be determined. The implicit guiding principles of the themes are readily identifiable by mature readers of the texts, but to my knowledge no one has adequately assessed whether "typical secondary school students" are able to cognitively grasp the continuity of the themes and use them as an aid during knowledge construction while reading the texts. It is of interest to note that Arnold Grobman, who was the initial Director of the BSCS Committee, states that "Whether this course should be prepared for the tenth-grade level, where biology usually is offered in American schools, or for some other grade level, was not debated seriously by the BSCS. The Steering Committee felt that placement of subject matter courses at different grade levels involves considerations beyond those of the specific competence of a group of biologists and educators and requires the attention of a much more diverse cross-section of American Society ---[10]." This apparent reticence to clearly specify the target audience for the innovative texts may have been an unfortunate oversight. Given the complexity of the "enquiry" concepts to be communicated and the rich weave of sometimes tacit themes that characterize parts of the texts, some additional attention to the cognitive developmental level of the target audience may have been useful in designing the texts and ancillary curricular materials. Amidst the diversity of students enrolled in many American secondary school biology classes, the differences in cognitive development between the tenth and twelfth grade can be substantial. Moreover, even within the period of time encompassing the tenth grade, detectable cognitive growth can occur; and instruction should be carefully organized and sequenced to complement and enhance this intellectual maturation. According to Piagetian theory and other cognitive models, this is period of transition when some students enter a phase of advanced formal logical reasoning capacity. However, there are wide individual differences in the pace and level of formal operational thought acquired during adolescence and young adulthood. Secondary school curricula should be designed with careful attention to this variance. In many respects, the BSCS group set out to make radical departures from existing practice and it is difficult to know to what extent they benefitted by application of some established principles of curriculum design.

For example as early as 1949 Tyler[11] proposed a seven-step plan for analyzing the many elements that go into curriculum planning and their integration into a sound curriculum model. This plan has been succinctly summarized and related to modern aspects of curriculum design in subsequent publications[12]. In brief summary, the seven steps entail: 1. assessment of student interests and characteristics, 2. identification of societal problems and trends, 3. the standard disciplines are synthesized so as to delineate the information of greatest worth, 4. the objectives identified in the foregoing steps are joined in a cohesive statement of aims, 5. the curriculum designer's particular conception of instructional goals is used as a kind of filter to refine selected objectives, 6. objectives are further examined for feasibility in the light of current learning theory, and lastly 7. a coherent sequence of instruction is assembled by arranging the objectives into an orderly pattern of educational experiences. It is particularly noteworthy that both steps 1 and 6 make explicit point of understanding the potentialities and limitations of the learner by direct assessment and in relation to current learning theory, in addition to understanding the socio-cultural dimensions that frame the environment for a curriculum innovation.

It is clear that the BSCS Committee made an earnest effort to understand the historical, cultural and scientific origins of their effort. Schwab[13] describes three phases in the historical development of the American science textbook, commencing with about 1890. During the first phase lasting until ca. 1929, the basic format of the American textbook was established. It largely was a compilation of factual information required for college preparation, and in a format typical of college content, but in a slightly modified form to accommodate the maturational level of the reader. In spite of the heterogeneity of secondary school students and their manifestly diversified career goals, the textbooks provided little content texture to accommodate the prospective liberally educated laymen as well as the college-bound specialist in the field. The curriculum material was drawn largely from the traditional academic disciplines: mathematics, the sciences, Latin, literature, history, and English. Although Schwab decries the list-like compilation of factual information presented in the texts, he is quick to acknowledge the merits of extant biology texts: "They may have been a morass of isolated facts and primitive generalizations, but they came closer to being the 'right' facts and generalizations for the biology of the time than we were to see in the next phase of American science education." In the second phase from ca. 1929-1957 the textbooks were modified to take into account the diversity of clientele in the secondary school, and although the earlier textbooks were extensively but not fundamentally modified, the changes and elaborations were in Schwab's view at the expense of the best feature of the earlier model - its clear validity in correspondence with the state of the originating science. To exemplify his point of the alienation of textbook content from the originating science, Schwab cites evidence that among the textbook writers in 1915, better that 50% were in the roster of *American Men of Science* , but by 1955, the figure had dropped to less than 10%. The third phase commencing in 1958, including the period of the BSCS effort, was intended to merge the best insights from practicing biologists with those of educational practitioners toward a truly comprehensive renovation of secondary school biology texts that would be both scientifically authoritative and educationally sound. It was particularly hoped that the laboratory courses, to permit students to progress at an academic pace appropriate to their level of development and to allow greater flexibility in pursuing divergent lines of investigation within the range of options provided in the auto-tutorial suite of activities[17]. In recent years, the potentials for individualized, high level inquiry learning have been dramatically increased by the introduction of computerized instruction. But at present, much of the power of these instruments for flexible, programmatic network-based, interactive learning appears to be poorly exploited. The potential to analyze student's knowledge structures, assist them in evaluating ways to improve their information processing skills, update and extend their knowledge networks, and amplify the generality of knowledge by application to diverse problem-solving contexts has not been fully developed. Much additional research and innovative product development is needed to more fully realize the interactive capacity of computer-based instruction. This is especially noteworthy with respect to the development of programs that flexibly adapt to the students' interests, their unique information processing styles, and their diversified enquiry strategies, as has been recommended by science educators to improve modern science curricula.

The current status of curriculum organization in the United States including kind of content, cognitive/practical objectives of instruction, and the categories of inquiry skills specified-in American science programs at the fifth, ninth and twelfth grades has been summarized by Miller[18]. The data were compiled from state curricular guidelines, classroom texts, and the findings of national studies. She found that there are overlapping similarities in the kind of content presented and the range of skills required at all three grade levels, particularly in the science curricula intended for general (non-science career) students. In general, the instructional objectives for basic science process skills, including knowledge of inquiry processes, comprehension, observation, and laboratory skills were emphasized more than the coverage of science content, further augmenting the conclusion that there is a general trend toward greater emphasis on process skills in science curricula as compared to knowledge structures. The legacy of the philosophy of the BSCS innovators, especially the strident call for more emphasis on "enquiry activities" in learning, and programmatic emphasis on the development of scientific reasoning skills, has had a clear effect beyond the texts prepared by the Committee. An examination of many current textbooks, some that originated in the second phase of American textbook history as outlined by Schwab, reveals greater emphasis on the history of science, investigative methodologies, more open-ended laboratory experiences, and greater opportunity for students to develop critical thinking skills and autonomy in rational, ordered thought. Increasingly, general biology texts are being written by teams of scholars rather than by single or multiple authors, further reflecting the laboratory courses, to permit students to progress at an academic pace appropriate to their level of development and to allow greater flexibility in pursuing divergent lines of investigation within the range of options provided in the auto-tutorial suite of activities[17]. In recent years, the potentials for individualized, high level inquiry learning have been dramatically increased by the introduction of computerized instruction. But at present, much of the power of these instruments for flexible, programmatic network-based, interactive learning appears to be poorly exploited. The potential to analyze student's knowledge structures, assist them in evaluating ways to improve their information processing skills, update and extend their knowledge networks, and amplify the generality of knowledge by application to diverse problem-solving contexts has not been fully developed. Much additional research and innovative product development is needed to more fully realize the interactive capacity of computer-based instruction. This is especially noteworthy with respect to the development of programs that flexibly adapt to the students' interests, their unique information processing styles, and their diversified enquiry strategies, as has been recommended by science educators to improve modern science curricula.

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Some Analyses of Biology Textbook Content

As an aid in understanding the major content themes in some current secondary school biology texts, and as a resource to be used subsequently in evaluating the representativeness of some biology test items used by the Second International Science Study examiners, a comparative summary of some textbook content is presented in Figs. 2.1 to 2.4[19-21]. These are matrices (e.g. Fig. 2.1) containing cells showing the number of pages devoted to given topics. The cells are categorized in rows by levels of biological organization (including scientific inquiry), and in columns according to biological content represented by taxonomic kingdoms (Monera, Protista, Fungi, Plantae, and Animalia). In coding the textbooks, only the expository content was considered. Questions at the end of the chapters and pictorial content were not given separate attention. Each page of text was examined and an overall judgement rendered as to the major emphasis of the content. This was based in so far as possible on the amount of space on the page devoted to the topic, not on the apparent emphasis based on the arguments presented in the text. While there are many suitable texts that could have been analyzed in this comparative survey, three were chosen to represent a moderately middle-ground or typical modern biology secondary school text. The BSCS "Yellow-Version," titled *Biological Science an Inquiry into Life*, is perhaps the most general of the three BSCS texts and is one of the more widely used BSCS books. The *Modern Biology* book is a long-established secondary school text that has been substantially modernized in recent versions. The text titled *Biology* authored by Oram was chosen since it appeared to be a general biology text of moderate difficulty. The relative breadth of content varies considerably across the three selected texts (Figs. 2.2 to 2.4). Although the coding chart has been used solely to record the number of pages devoted to each topic, it is also possible to use the chart to enter the number of higher level thought questions or other process-dimension items detected in the text. It has also been used in this study to classify test items into categories for further analysis (see Chapter Two). All of the coding of texts and questions was done by the author.

Figures 2.1 and 2.2 Outline of Coding Form (2.1) and Coded Chart for BSCS Textbook (2.2). Cyan.= Cyanobacteria, Eub.= Eubacteria, Alg.= Algae, Protz.= Protozoa, N.Vs. = Nonvascular, Vs = Vascular, Inv. = Invertebrate, Hu = Human. General represents content spanning across two or more Kingdoms. The number of pages that address each topic are entered in each cell of the chart. The box labelled Source at the upper left-hand corner contains the title of the book analyzed. (On Continuing Pages).

Figure 2.1 Outline of Coding Form

Source: LEVELS	KINGDOMS: MONERA Cyan	Eub	PROTISTA Alg	Protz	FUNGI	PLANTAE N.Vs	Vs	ANIMALIA Inv	Vt	Hu	GENERAL
MOLECULAR											
Structure											
Function											
Enzymes											
Metabolism											
CELLULAR											
Structure											
Physiology											
TISSUE/ ORGAN											
ORGANISMIC											
Morphology											
Anat./ Physiol.											
Reproduction											
Development											
Genetics											
Classical											
Molecular											
POPULATIONS											
Growth											
Adaptations											
Interactions											
Diversity											
Systematics											
Evolution											
COMMUNITIES											
ECOSYSTEMS											
Structure											
Development											
Stability											
BIOMES											
SCI. METH.											
Data anal.											
Exper. design											
Hist./ Phil.											

Figure 2.2 Coded Chart for BSCS Textbook

Source: BSCS *BIOL SCI INQ LIFE*	KINGDOMS										
	MONERA		PROTISTA		FUNGI	PLANTAE		ANIMALIA			GEN.
LEVELS	Cyan	Eub	Alg	Protz		N.Vs	Vs	Inv	Vt	Hu	
MOLECULAR											3
Structure											20
Function						1					2
Enzymes											4
Metabolism											10
CELLULAR											
Structure											15
Physiology											37
TISSUE/ORGAN											
ORGANISMIC											
Morphology											
Anat./Physiol.			3	10			17	19		85	
Reproduction				2			13	3	5		
Development									12	4	10
Genetics											
Classical					3		9	20	10	22	3
Molecular		5								2	17
POPULATIONS											
Growth										2	
Adaptations						5					
Interactions											5
Diversity								8			
Systematics	1	1	2	2	2	2	5	2		11	18
Evolution							2			35	57
COMMUNITIES											2
ECOSYSTEMS								3			
Structure							16				15
Development											4
Stability										6	9
BIOMES											7
SCI. METH.											
Data anal.											7
Exper. design										10	17
Hist./Phil.											13

The BSCS "Yellow-Version" text (Fig. 2.2) is more focused than the other texts, as would be expected, since the BSCS writers aimed to produce a text with a distinctive thematic focus. For example, the major points of emphases, based on pages allocated to topics, appear to be in general areas of plant and animal organismic biology, especially ontogenetic development and genetics. A substantial amount of emphasis is also given to systematics and evolution with substantial pages devoted to animal biology. Within this coding scheme, much of the molecular and cellular information was presented in a general context with comparative data among major biological taxa rather than clearly focused on one or more individual taxa. As is consistent with the aims of the BSCS writing group, a substantial number of pages were tallied for scientific methodology (ca. 50). As a simple quantitative index of diversity, the following formula was applied. $D = 1 - [(N - n)/ N]$; where D is the diversity index. N is the total number of pages coded, and n is the number of cells in the coding matrix that contains tallies. The value of D is 1.0 if $N = n$. It approaches zero as n becomes very small compared to N. The coefficient does not take into account density of tallies within cells in the matrix only the degree of dispersal of codes in the cells. However, it is sufficiently refined for the purposes of this analysis. The value of the index for the BSCS "Yellow Version" is $D = 0.09$. As mentioned above, based on this coding scheme, the BSCS text is clearly focused within major content areas. Fifty-nine cells were entered in the coding matrix (Fig. 2.2). Since the number of pages coded exceeds the number of cells in the matrix, the maximum diversity coefficient that could be generated is $D = 0.73$. Therefore, the ratio of the observed to maximum value is reported, i.e. 0.09/0.73 = 0.12. Thus, 12% of the maximum possible diversity is realized.

Modern Biology by Otto et al. (Fig. 2.3) shows greater diversity of content than the BSCS "Yellow-Version" based on this coding scheme. There are more pages with information on diverse taxonomic groups, especially at the organismic level. In terms of detectable content per page, there appears to be less emphasis on genetics, but only slightly more taxon-specific information at the molecular and cellular levels. There are, however, fewer pages explicitly devoted to issues of scientific methodology. Ninety-three cells were entered in the coding matrix; and $D = 0.15$, indicating quantitatively a greater diversity in emphases than in the BSCS text. Given a maximum diversity of $D = 0.74$ for this text, the proportion of the observed to maximum value is 0.15/0.74 = 0.20, or 20% of maximum possible diversity.

Figure 2.3 Coded Chart for the *Modern Biology Textbook* (On Continuing Page).

Figure 2.3 Coded Chart for the *Modern Biology* Textbook

Source: Otto and Towle *MODERN BIOLOGY*	KINGDOMS										
LEVELS	MONERA		PROTISTA		FUNGI	PLANTAE		ANIMALIA			GEN.
	Cyan	Eub	Alg	Protz		N.Vs	Vs	Inv	Vt	Hu	
MOLECULAR											
Structure		1		1							25
Function											1
Enzymes											1
Metabolism		3					7				10
CELLULAR											
Structure		1		1			2				10
Physiology											21
TISSUE/ ORGAN							1	6		7	1
ORGANISMIC											
Morphology			3	5	5	2	4	23	27	5	
Anat./ Physioi.			2	3	1		33	18	21	102	1
Reproduction		1	2	1	3	3	11	4	9	15	1
Development		2					4	2	1	1	1
Genetics										2	9
Classical		2					7	6	4	14	5
Molecular		4									
POPULATIONS											
Growth								3	1	2	4
Adaptations		1						2			1
Interactions											5
Diversity											2
Systematics	2	5	1	1	1		1	6	2	29	4
Evolution								1	3	11	10
COMMUNITIES											
ECOSYSTEMS											
Structure								1	6		7
Development											2
Stability							2		3	8	3
BIOMES											13
SCI. METH.											
Data anal.											
Exper. design											9
Hist./ Phil.											8

To a substantial degree, the third text *Biology* (Fig. 2.4) yields a pattern of coded pages very much like that of the *Modern Biology* text (Fig. 2.3). Ninety-five cells were entered in the matrix compared to 94 for the *Modern Biology* text. The diversity coefficient is D = 0.16. Based on the total pages coded, the maximum diversity value that could be generated is D = 0.76. The ratio of observed to total diversity is 0.16/0.76 = 0.21 (21% of maximum possible diversity). This value is very similar to text number 2 and more diverse than the value of 0.12 generated for the BSCS text.

Although this coding scheme is useful in mapping the distribution of biological ideas in a textbook, it cannot reveal differences in other significant parameters such as 1. style of writing and level of difficulty of the narrative, 2. development of themes; 3. continuity in, and logical rationality of, scientific arguments; and 4. the quality and abundance of higher order thought questions displayed in the text or in the chapter summaries. These issues are certainly of profound importance in judging the total characteristics of the texts. The matrices in Figs. 2.2-2.4 are intended only as profiles of emphasis in content. Furthermore, the full range of content emphasis was not determined by this application, since the unit of analysis was the page and its major content theme. Each page was examined and the content coded. based on the dominant theme in the narrative. No page was coded in more than one category. Thus, the coding is conservative and some references to major categories in the matrix may be under-represented by this parsimonious coding method. When coded by this method, the matrices provide only a general profile of content emphasis in some modern secondary biology textbooks. A finer analysis could be rendered by using a smaller unit such as the paragraph. This, undoubtedly, would resolve much finer textual variations. The present application was based on non-overlapping page counts; therefore, it was not possible to code a page more than once, even when several possible content categories were detectable. The paragraph unit of analysis is recommended for these finer discriminations. Finally, these content analyses are not intended to be, nor is it recommended that they be employed as, criteria for judging the quality of the texts. No judgement of merit is implied by the analyses. Other sources of information are available containing criteria for, and reports on, evaluation of textbook organization and quality[22-24].

While creative insights in curriculum design and textbook production are significant factors determining the composition and efficacy of American biological education, results of modern research studies hold increasing promise as sources of information to guide development of effective and efficient future biology educational experiences. Some pertinent current research findings in biological education are summarized in the next chapter as a broader context for the analyses of the recent findings of the SISS survey.

Figure 2.4 Coding Chart for the *Biology* textbook (On Continuing Page).

Figure 2.4 Coded Chart for the *Biology* Textbook

Source: Oram *BIOLOGY* LEVELS	KINGDOMS: MONERA Cyan	MONERA Eub	PROTISTA Alg	PROTISTA Protz	FUNGI	PLANTAE N.Vs	PLANTAE Vs	ANIMALIA Inv	ANIMALIA Vt	ANIMALIA Hu	GEN.
MOLECULAR											
Structure											20
Function											2
Enzymes											6
Metabolism					2		6		1		10
CELLULAR											
Structure											16
Physiology									5		17
TISSUE/ ORGAN								1	6	4	
ORGANISMIC			3	1							
Morphology	1	5		3	3	3	11	23	11		1
Anat./ Physiol.		6		6	3		22	17	15	57	
Reproduction		2		1	2	3	9	3	4	5	1
Development				2			3	1	7	4	12
Genetics											
Classical							8	5	2	9	3
Molecular		2							19		29
POPULATIONS							1	4	7		6
Growth										5	3
Adaptations							2	4	4		2
Interactions											9
Diversity				3	2						
Systematics		1	1	1	1	1	1	1	1		13
Evolution									13	7	10
COMMUNITIES	3							2			
ECOSYSTEMS											
Structure							2		5		15
Development							5				12
Stability										21	
BIOMES											
SCI. METH.											
Data anal.											3
Exper. design											3
Hist./ Phil.											12

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Chapter Three
STUDIES ON BIOLOGY ACHIEVEMENT

Introduction

Some pertinent, recent investigations of secondary school biology achievement are summarized here as background information for the analyses and discussion of the SISS findings presented in the final two chapters. Critical reviews of recent research on science teaching and learning have been published annually since 1973 in the journal *Science Education* [e.g.1,2], and elsewhere in other scholarly publications such as *Journal of Research in Science Teaching* [e.g.3], or those distributed by Science Mathematics, and the Science, Mathematics, Environmental Center (ERIC) at Columbus, Ohio. This review is not intended to duplicate these contributions, nor to provide a comprehensive analysis of current science education research in a critical perspective. Rather, this review will largely focus on the relationship of instructional strategies and classroom learning environments to biological literacy, including current studies of concept acquisition and the role of students' conceptions and misconceptions in biology learning.

Instructional Variables and Biological Literacy

Knowledge and Skill Acquisition.

The changing conceptions of how students learn science have consistently tended in recent years toward an information-processing or cognitive-constructionist model. This perspective assumes that students acquire new information by an active process of reorganizing information to make it compatible with existing knowledge structures. During this process, prior knowledge is mobilized, and by application of information processing strategies, both existing knowledge and incoming new information are modified to increase their compatibility and associational stability in memory[4,5]. To some degree, the information processing strategies are similar among individuals, especially for individuals of the same linguistic community, similar cultural heritage and educational background. In the absence of substantial similarities in the knowledge structures of students based on long-term learning, it is possible for the instructor to mobilize organizing constructs from recent common points in learning, or to create new models and "organizing schemas," that provide a common cognitive framework for building additional knowledge associations[6,7]. Furthermore, some similarities in learning strategies across individuals may be explained by common human species-specific hereditary factors that determine neurocognitive processes mediating primary perception and fundamental mechanisms of encoding new information[8]. However, increasing evidence also indicates that during maturation, learners acquire unique or idiosyncratic modes of information acquisition. In some cases, these "personal" strategies accrued during enculturation, though diverse across individuals, are equally effective for certain kinds of problem solving tasks. But, in some cases they may be very inefficient or even debilitating if they are of limited applicability or reinforce misconceptions.

A substantial amount of research in recent years has been directed toward understanding variations in information processing modes among different individuals when given similar learning tasks. In some cases the subjects are asked to report aloud what they are thinking as they proceed through problems or analyze information they are to learn. Consequently, insights are gained into the varied ways individuals approach information processing tasks. These studies can also elucidate what strategies are most effective in a given learning context and how individuals can improve their strategies to better assimilate and order information in memory to make it available for use in problem-solving or other generative applications[9-11]. In some cases, researchers adopt a particular research perspective or theoretical model to guide their inquiry, sometimes to the exclusion of other viewpoints. While such a pointed perspective can provide an orderly accumulation of knowledge within a research paradigm, in practical applications during curriculum design and planning for instruction, it is wise to consider a broad base of current theories. It is unlikely that a given psychological model is sufficiently comprehensive to provide insight into the multi-faceted requirements of designing a truly liberal learning experience. This includes adequate appreciation for multiple ways students of varying chronological age and intellectual maturity acquire information during varied modes of instruction; i.e. verbal communication, various forms of discovery learning and laboratory-based instruction. Moreover, the creative instructor may choose one of varied learning strategies to meet the joint requirements imposed by the logic of the content and the cognitive level of the learners. These strategies may include reception learning (e.g. oral communicated content), discovery or inquiry learning, problem-solving experiences, and other open-ended instructional approaches. The temporal placement and duration of these activities should be arranged to meet the manifold requirements of the students' background, quality and quantity of information to be acquired, logical constraints of the content, and educational history of the learner. A clear understanding of the student's prior knowledge structure, including major anchoring ideas in memory, intellectual skills available to transform and interrelate information, and degree of inter-connectedness of information in memory, is useful in making curriculum experiences more meaningful.

In large measure, information processing paradigms have emphasized the importance of helping students develop and refine their unique strategies of information processing and scientific reasoning skills toward enhancement of their particular psycho-linguistic educational heritage, and improvement of their ability to adapt to future learning environments. These studies have been summarized in current theoretical papers and research reviews[12-15]. For example, biology students who were taught to study information in quantities that complemented their cognitive processing capacity (CPC) and to chunk these quantities together in a study outline or ..gram format (i.e. to categorize incoming information into assimilatable related unit: ..rformed better compared to a control group. Moreover, correlations between CPC sc... ...l biology unit test scores accounted for 46% to 82% of the variance in the control group's biology test scores indicating the power of this variable in accounting for acquisition of some typical biology information[16]. Various strategies have been evaluated to improve the level of student co...ptualization in biology learning including: 1. the use of concept maps as organizing frameworks to order and clearly delineate multiple relationships among conceptualizations in teaching junior high school and secondary school science. Concept maps were also examined as an aid to teaching biology in inner city schools[17]; in this case, no statistically significant improvement was found, 2. the interaction of conceptual connectedness of information presented to students with their locus of control (internal decision-making referent systems versus external posited sources of. control) and its effects on higher order knowledge acquisition in biology[18], and 3. the effects of sequentially increasing the demands for independent judgement during a semester of laboratory exercises on acquisition of laboratory concepts in biology[19]. With respect to locus of control, externally oriented students benefitted from the presentation of information in a connected framework (concept map format) compared to controls, but inner-directed students were not dependent on this external organizing strategy. In general, some teachers achieve significant gains in laboratory concept attainment with the strategy of increasing demands for independent judgement, but the results were not uniform. This suggests that as often occurs in studies of subtle teaching strategies, the interaction of the method with other teacher characteristics can be significant in determining the success or failure of the intervention.

The management functions of the teacher, especially skills in matching content quality and quantity to student level of cognitive development, appear to be a major factor in determining success of biological instruction in more abstract or formal kinds of learning. In an analysis of genetics teaching using comparative case study techniques, the following management functions appeared to account for much of the success or failure of the students in mastering the content[20]: 1. the skill of the instructor in translating their knowledge of the content and curriculum into learning tasks that match the cognitive demands of the learners, 2. the instructor's efficiency in managing learning tasks and coordinating student activities to maximize curricular aims, 3. ability in rendering decisions that enhance the learning of the content, and 4. use of strategies to ensure that students have ample opportunity to acquire genetics information at a conceptual level.

Among other variables characterizing classroom climate or ambience, the gender of the teacher may influence the student perceptions of classroom processes. Lawrenz and Welch[21] report that students perceive classes taught by females as more formal, more goal directed, more diverse and as having more instances of teacher favoritism and friction between students. Classes taught by males were perceived as more difficult. Some of these differences in perceptions of male and female teachers may be explained by differences in the personality and content sophistication of the two groups. In a previous survey[22], female teachers were shown to be more positive in their attitudes towards science and more receptive to change, while male teachers scored higher on content knowledge. Hence, classes taught by males may be viewed as more difficult because of their stronger academic preparation in the science field, whereas, female teachers are perceived as more diverse due to their receptivity to change.

In addition to classroom climate, the mode of verbal interaction of the teacher, whether direct or indirect, influences student information sharing and knowledge gains. Students in an indirect teacher-guided group achieved better and participated more in class activities than students in a direct group[23] In general, teacher behavior that provides opportunities for students to define the direction of discussion, allows opportunity for student reflective thought during classroom dialogue, especially after higher level questions are raised, tends to favor higher order information processing and development of scientific thinking skills[24-26].

Acquisition of Scientific Thinking Skills

The students' efficiency in learning scientific thinking skills is influenced by their level of intellectual maturation (formal thinking capacity) as assessed by Piagetian measures. In a thorough and interesting review of current research on formal reasoning and science teaching, Lawson[27] concludes: 1. the Piagetian level of the student is a significant factor in determining their efficiency in acquiring higher order scientific reasoning skills; however, 2. performance on formal reasoning tasks can be substantially enhanced by appropriate focused teaching strategies to help the student develop specific skills, and 3. "The extent to which the training transfers to novel problems and contexts and even to novel reasoning patterns depends upon the length and richness of the training and the extent to which children are intellectually in control of their own actions." Padilla et al.[28] showed, moreover, that science process skills are closely correlated with formal thinking abilities ($r = 0.73$) and that teaching students process skills may influence their formal thinking capacity. In a study of the interrelationship among laboratory process skills during inquiry learning in secondary school biology, Tamir and Amir[29] reported that seven factors can account for performance on a twenty-one item laboratory inquiry skills test. These are in descending order of predictive power: 1. handling quantitative relationships, 2. explaining and assessing data, 3. conceptualizing and planning investigations, 4. summarizing results, 5. interpreting and concluding, 6. selecting form of presenting findings, and 7. designing experiments. The composite findings suggest some interesting practical and theoretical implications based on the associative links among the factors in cognitive structure. For example processes that previously were thought to be closely related such as conceptualizing investigations and designing experiments appear to involve different and, to a large measure, independent skills. This suggests that students who are highly skilled in the technical aspects of designing experiments including such critical factors as specification of treatments and varying independent variables, may not be skilled in highly abstract processes such as formulating problems and hypotheses that constitute the conceptual bases for the experiments. A similar distinction was found between drawing conclusions and interpreting data versus explaining and critical assessment of data. Tamir and Amir conclude that while the first pair involves relatively low level reasoning, the second requires abstract thinking combined with the ability to integrate and apply prior knowledge. In general, the findings suggest that these several independent factors require specialized attention if students are to develop inquiry skills, and they cannot be expected to accrue simply by unreflective manipulation of laboratory equipment.

Among the more formal skills that characterize literacy in biological education, hypothesis formation and testing is clearly fundamental to critical use of enquiry skills. Moshman and Thompson[30] concluded that the development of hypothesis-testing competencies can be conceptualized in terms of six discrete sequences, involving: 1. interpretation of the hypothesis; 2. making a distinction between using theories and testing theories; 3. recognizing that there may be multiple possibilities in seeking data to test the hypothesis; 4. differentiating between theory and data; 5. recognizing the merits of seeking evidence that falisfies as well as verifies the hypothesis; and 6. understanding the relation of truth and falsity in testing hypotheses. The latter distinction is often overlooked even by some college students who seem to see truth and falsity as symmetrical opposites, rather than understanding that a single falsification of a hypothesis has greater decision value than a single point of verification. Apparently, this lack of distinction may arise from an incomplete appreciation of the complexity of most natural phenomena and the variation in results of tests that one may encounter across widely different testing contexts. The development of more sophisticated strategies in testing hypotheses relative to these six categories appears to be related to cognitive maturity, especially the level of formal thought.

In a survey study of 649 students spanning kindergarten to grade 12, Lawson and Hegebush[31] examined causal hypothesis testing strategies of the subjects in relation to their chronological age and probable Piagetian cognitive level. They presented students a puzzle picture of a natural setting containing two trees on a grassy plane, one tree was surrounded by grass cover, the other with barren ground under its leaf canopy. The following questions were investigated: "1. At what ages are students able to make observations of the sort called for in the Trees Puzzle and raise the appropriate causal question? 2. At what ages are students able to generate causal hypotheses? 3. Once causal hypotheses are generated, what sorts of strategies do students use to test them? and 4. What changes in strategies occur across age?"

The percentage of students who generated a causal question when presented with the picture puzzle ranged from 10% in grade K, 40% in grade 4, 66% in grade 6 up to 84% and 94% respectively in grades 10 and 12. These data suggested that the steady increase with age of students who were able to generate causal questions is related to increasing general awareness of cause-effect relations, which is a likely prerequisite for the development of effective hypothesis testing strategies. These data, moreover, may clarify why effective strategies for hypothesis testing develop in most individuals at about the time of adolescence or not at all for some individuals. In general, ability in generating hypotheses improved across grade levels and the quality of strategies for testing hypotheses generally improved markedly after the sixth grade. The percentage of students who proposed methods of direct observation for testing their hypotheses increased from ca. 5% in kindergarten, to 44% and 57% respectively in grades 10 and 12. The use of formal logical reasoning strategies increased markedly after the sixth grade, but less than 30% of the twelfth grade students in the sample were able to propose a scientifically reasonable method for testing their ideas. This is consistent with other Piagetian-type studies that show many secondary school students are still concrete operational with respect to many thought processes characteristic of more advanced science and may limit their capacity to efficiently acquire advanced science process skills over relatively short instructional intervals.

In a more general view, the question arises as to how much change in science process thinking skills can be expected to occur within a period of one academic year of biological instruction. Early in the development of the BSCS program, a "Process of Science Test" was constructed and formally evaluated with 28,173 secondary school students[32]. This forty item test contained questions on interpreting tabular data and graphs, designing controlled experiments, identifying significant from insignificant or invalid findings based on brief summaries of experiments, and distinguishing between scientific versus non-scientific ways of explaining phenomena. After one year of biological instruction in the tenth grade, the gain in mean score on the test was from 22.0 to 26.1. Furthermore in a comparison of students who used BSCS materials compared to control groups who received "non-BSCS materials," the initial score on the science for the BSCS group was 22.1 and the final mean score at the end of the year was 26.4. This is compared to a change from 21.8 to 24.4 for the control group. Thus, even with a moderately intensified program for inquiry teaching in biology at the tenth grade level, the gains as assessed by this kind of test may not be dramatic. However, this study was done as part of the test validation, and further analyses of this kind with large groups are needed to determine the generality of the conclusions. More particularly, investigations of the affects of inquiry teaching on specific scientific skills, rather than the more general scientific literacy represented by the BSCS test, may be helpful in delineating areas of most efficient cognitive growth.

Some additional science process tests[33-35] have appeared in recent years and may be more appropriate for assessing specific areas of growth in scientific reasoning. These include tests of integrated science process skills that span across scientific disciplines, encompassing questions that test for abilities in interpreting graphs, evaluating hypotheses, understanding a research question, and selecting strategies to answer it. In relation to the model of scientific literacy presented in Fig. 1.1 of this monograph, some of the items approximate psycho-linguistic competencies approaching categories 1E and 1F. It is difficult to judge, however, to what extent some of the more advanced questions approximate the most elaborate form of literacy mapped in quadrant IV of the model. This is due in large part to the fact that the tests are of a paper and pencil type and do not permit the kind of dialogue suggested by the highest level of literacy indicated in quadrant IV. Other recent tests, suitable for assessing biological literacy, address more specific science reasoning skills as represented by a group test of formal operational logic in the content area of environmental science[36]. Although scientific process skills have occupied much recent attention in biological education, the role of higher order knowledge structures in learning biology and the role of students' accurate conceptualizations and misconceptions in learning has assumed increasing importance.

Biology Students' Conceptions and Misconceptions

Considerable attention has been directed to the possible enabling effects of students' highly-coordinated, accurate conceptualizations on biology learning as opposed to misconceptions that may debilitate or hinder further learning[e.g. 37,38]. The quantity of verbal material to be mastered in science, especially the rich vocabulary in the biological sciences, presents an ironic dilemma. On the one hand, mastery of highly developed and inclusive concepts in the life sciences can provide a knowledge structure that mediates enhanced sensitivity to and cognitive representation of natural phenomena. Clearly, however, an over emphasis on rote learning of numerous isolated facts and concepts can vitiate the organizing capacity otherwise mediated by a well-organized network of conceptions. Some balance is required to ensure that middle and secondary school biology students benefit from the challenge of mastering a wide range of conceptual phenomena at a time in their development when perceptual acuities and seminal knowledge structures are developing. In the physical sciences, some misconceptions that interfere with further learning appear to arise from naive assumptions gained during early childhood. Therefore, the question arises to what extent biological misconceptions also may be rooted in early educational experiences[39]. Unlike the physical sciences, it appears that acquisition of biological conceptions follows a natural accretion pattern whereby knowledge structures are built-up under the guidance of teachers who mediate interpretations of the biological phenomena. Hence, there are less likely to be deeply rooted biases about how biological phenomena occur by the time students arrive at the secondary school level. Nonetheless, "conceptual change teaching strategies" are undoubtedly beneficial throughout the course of schooling to provoke students to reconsider in depth how they are organizing conceptual explanations. Moreover, poorly formed conceptions, and limited understanding of cognate concepts from the chemical and physical sciences, may interfere with learning of physico-chemical and mathematically based concepts in biology.

Given the diverse array of concepts to be mastered in science, especially biology, and the number and complexity of terms to be acquired, Yager and Yager[40] examined the maturation of 9-, 13-, and 17-year-old students' understanding of eight science terms during their progress through middle and secondary school in a midwestern school district. The terms were volume, organism, motion, energy, molecule, cell, enzyme, and fossil. Four of the terms were from the physical sciences, four were from biology and one was possibly also categorized as an earth science concept. With three of the eight terms, 9-year olds were as knowledgeable as 17-year old students. For the remaining five terms, increasing mastery was attributed to increasing student abilities to read, increases in student experiences with school science and testing procedures, maturation and development of reasoning across grades, and the relative emphasis of science content/terminology for the various age levels. Although these grade level comparisons show little effect of instruction on improvement from intermediate to high school levels, there is some evidence that there is a direct relationship between concept emphasis in secondary school biology textbooks and concept achievement level[41]. This suggests that focal emphasis on development of concepts within a grade level may be efficacious even though more general concept learning is less pronounced across broad grade levels. In general, these findings are also consistent with earlier reports of little growth in scientific conceptual literacy across grade levels in the secondary school[42]. On the whole, there is more marked progress from 9 years to 13 years of age suggesting possible contributions of cognitive maturation as the students progress beyond the concrete level[43].

In a similar analysis, intermediate school and junior high school (grades 3 to 9) student's conceptualization of the meaning of living and nonliving was examined using Piagetian concepts[44]. Piaget identified four stages that characterize the development of a concept of life during maturation[45]:

Stage A (age 6-7) wherein any object exhibiting activity assessed by auditory stimuli, or visual tracking of movement, is considered to be living.
Stage B (age 8-9) marked by greater cue specificity - any object moving is considered to be alive.
Stage C (age 9-11) where objects exhibiting spontaneous movement are considered to be alive and also to have consciousness.
Stage D (age 11 and higher) in which only living things things are identified as alive and possessing consciousness.

The general property of perceiving non-living things as animate is categorized as animism. Four questions pertaining to this misconception were addressed[46]:

"1. How well can students differentiate between living and nonliving?
2. What criteria do they employ in the classification?
3. Do they relate different meanings to the concept 'alive'?
4. Do they relate different meanings to the same trait, such as movement, when applied to a dog or to clouds?"

Interview techniques and questionnaires were used to obtain data relative to the four questions. During interviews, the students were shown eight pictures, four of living things and four of non-living entities, but possessing motion or other attributes that might be misconstrued as conferring life. Among the living objects, some were plants, others were animals or animal eggs. Interestingly, animal eggs (though belonging to the animal kingdom) were considered by many students (50%) to be not alive. This is compared to 40% who classified seeds as not alive. With respect to other living forms (plants and fungi), trees and mushrooms were considered alive less often than an herbaceous plant. Among inanimate items, human artifacts (e.g. television or train) were considered alive less often than natural phenomena such as a river or the sun. With respect to the four major questions, the following points are briefly summarized. Living versus non-living is distinguished most often on the basis of movement especially with respect to animals or inanimate objects, whereas growth and development were the most widely applied indicators of life in plants and embryos. A noteworthy finding is that a large proportion (21%) of subjects used self-activation as an indicator of nonliving for man-made objects such as trains and televisions. In general, as grade level increased, subjects used biological criteria for differentiating between living and non-living and referred less to the functional significance to humans. This may be consistent with data cited above that biological conceptions are less dependent on "intuitive" understandings and more related to adult mediated learning. In general, it is important to note that many individuals exhibit highly context dependent responses in making judgements between living and non-living things. Correct assignment among one form of living things does not mean that performance will be equally accurate with another form. For many respondents, the life of humans and animals was very different than that of plants, embryos, or inanimate objects. Moreover, life of a dormant seed may be perceived quite differently from that of a germinating seed. Likewise, the knowledge that life originates from life does not prevent some respondents from believing that seeds and eggs are not alive. This may represent a lack of formal operational skill in recognizing inconsistencies in class inclusion arguments.

A similar possible interaction between Piagetian developmental stages and acquisition of concepts about, and operations of, science process skills has been reported[47]. Students may not be able to acquire certain process skills until the appropriate cognitive level is reached. Evidence suggests that the probability of a student being able to formulate hypotheses before the abilities to conserve, use proportional reasoning, control variables, and use combinatorial logic is quite low. A possible synergistic effect of learning integrative process skills on basic cognitive reasoning development may exist, but the trend in the data suggest that these processes are hierarchically ordered and care should be used in designing curriculum programs to develop subordinate logical skills before proceeding to more inclusive ones.

A learning hierarchy is also implied in students acquisition of knowledge about food webs[48]. The relationships among organisms in a food web, progressing from primary producers through a network of predators and prey, are governed by rule-like principles and should be amenable to hierarchical learning. One of the SISS items (Appendix A, p. 5) assesses knowledge of food webs and is discussed further in the results section of this report. A skill hierarchy[48] leading to the ability to determine how a change in the size of one population can affect another population in the same web, but not on the same trophic chain, was developed and tested previous research. Nine skills in ascending order included the following: Skill 1. "Given a food web diagram, determine the effect of a sudden size change in a prey population on its predator population." Skill 4. "Given a food web diagram, determine the effect of a sudden size change in one population on a second population, not located on the same food, when the effect is transmitted along only one route." Skill 9. "Given a food web diagram, determine the effect of a sudden size change in one population on a second population which is not on the same food chain, when the effect may be transmitted along more than one route." Simultaneously, five types of misconceptions about food web dynamics were identified: 1. Students tended to interpret food webs as though they were a simple food chain, neglecting the effects of a change at one node on multiple nodes connected to it. Alterations in a node were followed only along one chain. 2. Sixteen percent of the population failed to realize that changes in a population have indirect effects on other populations even when they are not directly related by predator prey relations. Some students assume that variations in one population can only influence other populations related to it as predator or prey. The other systemic effects are neglected, even after instruction in food web dynamics. 3. Predators located at a higher point in a food web prey on all other organisms located below it, without regard to lines of predator-prey relationships (ca. one-fifth of the sample held this misconception). 4. Changes in the size of a prey population has no effect on the size of the predator population (low occurrence, 6% of the subjects). 5. Only four percent of the students held the false conception that if the size of one population in a food web is altered, all other populations will be altered in the same way. These data suggest that carefully ordered learning sequences emphasizing the cumulative nature of hierarchically arranged rules can enhance teaching of systemic or network type phenomena. Likewise, with clear awareness of the likely misconceptions students may bring such learning tasks, proper ameliorative instruction can be taken at the appropriate stage in instruction. Additional sources of insights into students' conceptions and misconceptions in biology have been published on major abstract constructs including: 1. cell processes and photosynthesis[49-51], 2. classification systems and natural selection[52,53], 3. physiology and circulatory system[54], and 4. ecosystems[55], and broad areas of biological content[56,57].

Among other areas of abstract learning involving systemic thinking, genetics has been widely recognized as among the most difficult for many secondary school students. The combined results of several studies[58-61] on antecedent learning requirements and micsconceptions in genetics suggest the following conclusions:

> 1. The process of meiosis including chromosomal separation and halving of the chromosome number is not acquired in a sufficiently generalizable way to apply to reproduction. Consequently, students fail to realize that the egg and sperm carry only one half of the parent chromosomal complement not the diploid complement.

2. The mitotic and meiotic events are acquired as figural or iconic constructs (learned as pictorial or diagrammatic representations). Hence, students have difficulty applying symbolic labels to meiotic products during gene segregation and recombination. There is insufficient familiarity with use of symbols in representing biological phenomena.
3. Students lack the formal operational skills of combinatorial reasoning and controlling of variables; therefore, they have difficulty in systematically analyzing the combinations of alleles that can occur during fertilization.
4. There is insufficient prior application of proportional and probabilistic reasoning prior to the genetics learning. Thus, students lack sufficient knowledge of these mathematical constructs in the context of biological phenomena to apply them efficiently in genetics problems.
5. Insufficient discrimination learning during concept acquisition leads to micsconceptions about categories of phenomena. For example, students confuse amino acids and nucleic acids, or fail to discriminate between amino acids as a component part of proteins versus protein molecules as a separate structural and functional entity.
6. The concepts of allele, gene, and chromosome are not sufficiently differentiated cognitively leading to confusion of events during gene segregation, pairing of alleles, expression of traits by pairs of alleles, and analysis of phenotypes based on genotypes of the parents and offspring.

Further analyses of these topics will be made in a more practical context in Chapter Six.

Predictive Models of Achievement

Our ability to predict academic achievement over extended time periods, and in relation to variables that are significant in curriculum design, is limited. There are numerous student and environmental variables that must be taken into account in creating mathematical models to accurately predict achievement over long time periods. Nonetheless, in recent years some innovative approaches have been used toward the creation of mathematical models that will predict short or long term learning. Walberg[62,63] has used a statistical regression model based on an economic production function to create a "Model of Educational Productivity." The model has been applied to understanding factors that contribute to scientific skill acquisition, other variables of significance in biological education, and the development of scientific literacy. It can be used to determine some of the complex socio-cultural and educational variables that predict educational achievement. This is a wholistic approach using multivariate type statistics to predict the effects of several variables on educational gains.

Several studies have critically analyzed the merits of this approach and established guidelines for application[e.g.64-66].

Aldridge[67,68] has developed a mastery model of learning that considers several variables including prior learning, motivation, and time on task in predicting achievement over extended periods of time. This model, based on an exponential function, may be useful with further refinement for predicting how much practice is required to bring students to mastery level in a subject area. Increased precision in estimating time required to master content is clearly a useful tool in coordinating curriculum experiences to ensure that all students have sufficient opportunity to realize their potential and to receive appropriate instruction to produce criterion-referenced achievement.

Recent interest has increased in applying neuroscientific theory to understanding learning[e.g.69-71]. A neuromathematical model[72,73] of information processing and knowledge acquisition has been developed that predicts short-term learning using variables that include the intellectual ability of the learners, their prior learning and organizing ability brought to the learning task, quality and quantity of the information presented, and motivation. This model has been shown to accurately predict science learning by adolescents and may be helpful, with further refinement, toward predicting the kinds of information structures needed to enhance science achievement for students of varying information-processing ability. Among other contributions, this model provides insight into fundamental neuro-psychological processes that limit or potentiate verbal learning.

A comprehensive model of science learning incorporating Piagetian theory with neuroscientific paradigms has been proposed by Lawson[74]. This model utilizes a neural network theory to predict the kind of learning environments that may potentiate among other factors scientific skill achievement. The model, based on Grossberg's neural modelling principles of learning, perception, cognition, and motor control, includes an explanation for development of reasoning patterns including a model of sensory-motor problem solving. Lawson proposes that the latter pattern of problem solving is universal and can be used to explain the ontogenetic development of certain higher order reasoning skills. Among other implications, Lawson suggests "Students are taught strategies but they are seldom confronted with the diversity of problems needed to provoke the sort of close inspection of problem cues necessary to link cues with strategies, and tentative results with implied consequences.[75]" These limitations may also interdict acquisition of additional higher level thinking skills, and therefore adequate attention to early maximal development of sensory-motor problem solving skills seems to be a significant part of early schooling.

Each of the foregoing models provides partial perspectives on the complex task of predicting learning in relation to variables of interest to school practitioners and administrators. Ultimately, as is the ideal in a mature science, we trust that a unifying model of the phenomenon of learning can be constructed that will allow us to better understand the fundamental biology of learning, and also to better predict those conditions that enhance science learning by students of varying characteristics in relation to content of varying complexity and abstractness.

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Chapter Four
THE SECOND INTERNATIONAL SCIENCE STUDY: RATIONALE, METHODOLOGY, INSTRUMENTS

Origin and Rationale

The Second IEA Science Study (SISS) was sponsored by the International Association for the Evaluation of Educational Achievement (IEA), incorporated in 1967 as an assembly of educational scholars with multi-national research interests. The purpose of the SISS study was to assess international science education achievement following somewhat the design of an earlier study sponsored by IEA in 1970. Comber and Keeves[1] have presented the rationale and major findings for the international comparisons in that study, and Richard Wolf[2] has summarized the organization of the study and presented some of the results of the United States participation. The work of the Second IEA Science study was begun in 1980. Each of the participating research teams in twenty-four countries provided their own funding and collaborated equally in devising the rationale, constructing and assembling existing test items to be most representative of the curriculum in all countries, and establishing uniform procedures for testing and gathering data. Thus, every effort was made to ensure standardized construction and administration of test instruments while also permitting maximum collaborative interaction and equality of input from all members of the internationally assembled researchers. At this time, 17 of the 24 participating countries had completed their reports. Since the major details of the history, rationale, construction of test items, and administrative procedures of the international study are presented elsewhere[e.g.3,4], only a brief summary, pertinent to the assessment of biological achievement in the United States, is presented here.

Basic Methodology

Three populations, stratified by age, were assessed in each country : Population 1 consisted of either all 10-year olds or that grade in which most 10-year olds were enrolled, Population 2 consisted either of all 14-year olds or the grade in which most 14-year olds were enrolled, and Population 3 was all students studying science in the final year of secondary school. In the United States sample, Population 1 was students in the fifth grade (mean age = 11:3), Population 2 was ninth grade students (mean age = 15:4). In the United States, first year biology (primarily tenth grade) and first year chemistry (primarily eleventh grade) students were also tested; however, a few students enrolled in basic biology in the eleventh or twelfth grade were also included. Population 3 contained three subgroups based on the course of study: advanced biology (3B), chemistry (3C), or physics (3P). The mean age for all students in the United States Population 3 was 17:7. Students in Population 3B were largely from the twelfth grade, but some who were enrolled in second year biology in the tenth or eleventh grades were also included. The results of the research reported here will concern only the biology students; i.e., those in first year biology and Population subgroup 3B, advanced biology. The number of students participating in each group is reported in Table 4.3 which also contains reliability indices of the tests. United States students to be tested were not individually selected, but were taken as whole classes in randomly sampled schools based on carefully prescribed sampling plans to ensure that the schools chosen were representative of those in the nation. The sample design and data collection were done by the Research Triangle Institute (RTI) of North Carolina. The sample contained more than twenty thousand students in the three populations. Representativeness of the sample schools was established by standard random sampling protocols and by applying an analysis of "Marker variables" to ensure that the selected sample was indeed statistically representative of our nations schools based on several key variables that might be expected to influence the quality of schooling and educational progress of the students[5]. For example, with respect to the proportion of males to females in the 10 to 14 year age span, the national figure is 0.51, and the proportion in the SISS Population 2 is 0.49. On other key variables such as Father's Education, the national median is 12.6, and for the SISS Population 2 sample is 12.9. These data indicate that with respect to these marker variables, which appear to be good indicators of overall representativeness, the samples are satisfactorily representative of the total population. Even with this great care, one must note at the outset that Population 3B came from only 43 schools and contained 630 students. This small sampling base clearly limits the strength of conclusions that can be drawn for this group. Based on national statistics[6], the number of schools used for the first year biology sample is ca. 0.4% of the total, and for population 3B is ca. 0.15% of the total. Given the heterogeneity of American schools, especially the diversity of curricula employed, variations in policy and philosophical perspectives of the local officials and teachers, and the broad potential differences in administrative theory relative to school organization and personnel; it is wise to keep in mind that these samples from a relatively small percentage of U. S. schools, may have some unrecognized biases. Overall, however, considerable effort was made to ensure a valid sample using state-of-the-art sampling design.

Administration of Instruments

Data collection occurred in two phases. The first phase (1983 to 1984) provided background data, but did not test the populations considered here. The second phase was in 1986 and included the two populations considered in this report (Table 4.1). The biology content tests were presented first followed by questionnaires and background knowledge tests including a word knowledge test and a mathematics test.

Table 4.1 Data Collection Plan *

GRADE	SESSION 1	SESSION 2
First Year Biology →	Achievement Test I →	High School Science Booklet 2 Student opinionnaire Word Knowledge Test Mathematics Test
Second Year Adv. Biology →	Achievement Test II →	

*Note: After taking the appropriate achievement test, all students responded to the instruments listed under Session 2.

Instruments: Content tests, Questionnaires and Other Data Gathering Devices

A thirty item biology achievement test was prepared for each Population (Biology Test I, Appendix A; and Biology Test II, Appendix B). The items in the test were selected so as not to favor any one country or group of countries participating in the study. Moreover, some items contained in the test were identical to those in the first study sponsored by IEA. These "bridge" items provided a core for comparison of results with the first study. There were also 18 common items ("anchor" items) in the two tests for first year and advanced biology students. This allowed performance comparisons between the two groups. A math test (15 items) of appropriate difficulty was administered to each Population and contained items on scientific notation, operations with exponents, reasoning with equations, geometry, and trigonometry. Information on student gender, expectations about further higher education, patterns of homework and leisure activity, and information related to the socio-economic status of the family were obtained using a student questionnaire (16 items) contained in the same book as the math test. The questionnaire was followed by an opinionnaire (28 items) to assess student perceptions about the merits of science to society, professional roles of scientists, and the nature of scientific cognitive and laboratory activities, and the attractiveness of science and/or science teaching as a career. A science learning inventory

(24 items) assessed key aspects of the classroom teaching/learning environment, including whether or not a textbook is used, the organization of lesson activities, degree of student autonomy versus teacher-structured activities, and the occurrence, organization, and type of laboratory activities, etc. The last inclusion in this test booklet was a word knowledge test containing 30 items each composed of a pair of words to be categorized by the respondent as "Same" or "Opposite" in meaning.

Hereafter, the above tests will be cited respectively as "Biology Test", "Mathematics Test", "Questionnaire", "Opinionnaire", "Science Learning Inventory", and "Word Knowledge Test." For reasons of parsimony, the biology content test for the first year biology group will be designated Biology Test I; and for the advanced biology group, Biology Test II. In addition to these instruments distributed to the students, a "School Questionnaire" was distributed to each of the participating schools. This instrument ascertained the community urban status, population information for those served by the school, class scheduling and laboratory usage, and requirements for graduation. The teachers also completed a "Teacher Survey" which among other areas assessed the teacher's academic background in science content, professional education, etc. Information was also collected from the teacher for each test item as to the "Opportunity to Learn" the content in the item.

Biology Content Tests

Three indices of test validity were used. The first index was a curriculum relevance index and measured the extent to which the test was of equal appropriateness for all curricula of the seventeen participating countries. The second index examined the relevance of the test items to the national curriculum. A third index assessed to what extent a national curriculum was representative of those of all the countries participating in the study. A summary of the validation process and validity indices are presented in Appendix 8 of the preliminary report of the international results of the Second IEA Science Study[7].

The reliability coefficients (Cronbach's alpha) of the Biology Content Tests and those for the Mathematics Test based on the results of the United States sample are presented in Table 4.2. In addition to the total test reliability, an attempt was made post-facto to identify groups of items within the test that seemed to form a natural subset based on common biological or mathematical content. The items in Biology Test I are also coded according to content into seven categories: 1. Animal Biology, 2 Cell biology, 3. Data Interpretation and Experimental Design, 4. Ecology, 5. Evolution, 6. Genetics, and 7. Plant Biology. This was not done for Biology Test II since the size of the student sample appeared to be too small to make such fine distinctions. The designations were made on the best judgement of the major emphasis of the question content. In some cases, a question could be assigned to two or more categories based on component parts of the content, but an overall judgement was made to force each question into what appeared to be the most representative category. These categories for Biology Test I will be cited in subsequent discussions, where appropriate, merely as a convenient way of ordering information into manageable blocks. However, it is clear that in all cases, the reliability of these subsets is far too low to use them in further statistical analyses.

Table 4. 2 Total Test Reliability And Data By Content Subgroups

ITEMS	BIOLOGY I	ITEMS	MATHEMATICS I
	N = 2,582		N = 2,677
Total Alpha	0.80	**Total Alpha**	0.75
Cellular 5, 13, 17, 22	0.28	Basic Math. 1, 2, 4, 10, 15	0.53
Plant 3, 14, 27	0.21		
Animal 1, 2, 11, 15, 21, 26, 30	0.45	Proportions 3, 5, 6, 8, 13, 14	0.54
Ecology 4, 7, 8, 12	0.45		
Evolution 16, 19, 29	0.32	Geometry, etc. 7, 9, 11, 12	0.32
Genetics 18, 23, 24, 25	0.28		
Data Analysis, etc. 6, 9, 10, 20, 28	0.52		
	BIOLOGY II		MATHEMATICS II
	N = 659		N = 645
Total Alpha	0.76	**Total Alpha**	0.75

The low reliability is not entirely surprising given the post-facto nature of the groupings and the small number of items in each subset. The test apparently was not conceived to assess major subsets of biology and mathematics content, even though there are clear content categories that can be identified among the items. Thus, as is often the case with post facto categorization of test items into subtests, there is a low probability that the items will constitute a sufficiently reliable set of questions to permit detailed analyses.

To further display the range of content areas represented by the test items, and their categorical frequencies (Fig. 4.1), the items in Biology Test I have been coded using the same content analysis grid as used for three secondary school biology textbooks (Figs 2.1 to 2.3). This grid shows that the content coverage of the items is very similar to that of the emphases in the three textbooks. The highest density of tallies occurs in the categories of plant and animal organismic and population biology. Sixteen of the thirty items fall within this major set of categories. Six tallies occur in molecular and cellular biology categories, and the remaining eight are distributed among evolution, ecosystems structure, and scientific methodology. Hence, it appears that relative at least to the three textbooks examined, the test items are well distributed to represent secondary school textbook emphases. As a measure of diversity, a simple diversity index was employed:

$D = 1 - [(N - n)/N]$;

where N is the total number of test items, and n is the number of subgroups (matrix cells) containing items within the content grid. Thus, if all of the items were distributed among different content subgroups, the diversity index would be unity. That is $N = n$ and $D = 1.0$. To the extent that items are concentrated in groups, n becomes increasingly smaller, and D approaches zero as a limiting value. This is a modification of the diversity coefficient used in Chapter Two to analyze textbook content diversity.

Based on this coefficient, $D = 0.87$ for all test-item cell entries in Fig. 4.1 (p. 56). This indicates that the items tend to be fairly comprehensive in their content emphasis. If we examine only the rows to determine how well the test items are distributed among major biological concept levels, we obtain $D = 0.50$. This lower value is not surprising, since as noted for the textbook content, the test items emphasize organismic and population concepts.

With respect to the categorization of test items from the Biology Test I in Table 4.3, the data have been further grouped according to the major category represented by blocks of cells in the coding chart. Cell Biology includes all of the categories checked across kingdoms for Cellular, Plant Biology are all categories within the plant kingdom at the organismic level, likewise a category for Animal Biology was assessed, Ecology contains all counts across kingdoms in the Ecosystems block, Evolution contains all counts across kingdoms for the row category (Evolution). In similar fashion, all counts in rows were used for categories of Genetics, and for Scientific Methodology. The percentage of total items within each subcategory is as follows: 1. Cell Biology (13.3%), 2. Plant Biology (10%), 3. Animal Biology (23%), 4. Ecology (13 3%), 5. Evolution (10%), 6. Genetics (13.3%), and 7.

Scientific Methodology (17%). For purposes of comparison with textbook content emphases , the distribution of page counts for the BSCS text, *Biological Science: An Inquiry into Life*, is expressed as the percentage of total pages within each corresponding category: 1. Cell Biology (14%), 2. Plant Biology (8.3%), 3. Animal Biology (23%), 4. Ecology (10%), 5. Evolution (15%), 6. Genetics (14%), and 7. Scientific Methodology (8%). The latter is a low estimate, since many pages contain allusions to, or descriptions of, scientific enquiry topics, but since pages were coded based largely on the dominant ideational content, the amount of scientific methodology coded was in fact less than the total in the textbook. The sum of the percentages is not 100% due to the presence of additional content areas in the book, e.g. taxonomic classification, that are not included in the categories represented by the Biology Test items.

The percentage distribution of Biology Test items within these categories and the corresponding percentage data for content emphasis, based on page counts in the BSCS text, are remarkably similar. As further evidence, the percentage page counts distributed within the content subcategories was determined for *Modern Biology* by Otto and Towle. The distribution by categories is: 1. Cell Biology (16%), 2. Plant Biology (10%), 3. Animal Biology (46%), 4. Ecology (7%), 5. Evolution (4%), 6. Genetics (9%), and 7. Scientific Method (3%). This distribution, though less similar to the test item distribution than found for the BSCS text, is still reasonably similar. This further supports the conclusion that the Biology Test I is well constructed to represent American secondary school curricula, based at least on comparison to some widely used textbooks. No distributional analysis for items in the Population 3B Biology Content Test was computed, since this advance placement group represents college level biology and no corresponding analysis was done for college level biology texts.

The difficulty index (percentage of respondents who chose the correct option) for each item in the Biology Test I is presented in Table 5.1 along with other data used in discussing the results of the study. This Table also contains the proportion of students who selected each of the options (A to E) for each test item. The bold face entry marks the correct option. This, therefore, is the proportion of students who correctly answered the question. Table 5.2 presents the same analysis for the Biology Test II. In each of these Tables, the items are also classified according to their most likely position relative to the Scientific Literacy Model (Fig. 1.1) and whether they are science-process items (involving data analysis, experimental design, etc.) or non-process items.

Figure. 4.1 Coded Chart for Biology Test I Items (On Continuing Page)

Figure 4.1 Coded Chart for the Biology Test I Items

Source: S.I.S.S. BIOL. TEST I	KINGDOMS										
	MONERA		PROTISTA		FUNGI	PLANTAE		ANIMALIA			GEN.
LEVELS	Cyan	Eub	Alg	Protz		N.Vs	Vs	Inv	Vt	Hu	
MOLECULAR											
Structure											1
Function											
Enzymes											
Metabolism											1
CELLULAR											
Structure									1		
Physiology							1				2
TISSUE/ ORGAN											
ORGANISMIC											
Morphology									1		
Anat./ Physiol.							1		1	2	1
Reproduction											1
Development											1
Genetics											
Classical								1	2		
Molecular										1	
POPULATIONS											
Growth										1	
Adaptations							1	1	1		
Interactions											
Diversity											
Systematics											
Evolution									1		1
COMMUNITIES											
ECOSYSTEMS											
Structure								1	1		1
Development											
Stability											
BIOMES											
SCI. METH.											
Data anal.											
Exper. design							1		2		
Hist./ Phil.											

Some Comments on Item Construction and Content

Although the total distribution of items is rather consistent with textbook content emphases, it is lamentable that there were so few items clearly directed toward achievement in human biology. This is consistently an area of major emphasis in United States secondary school texts. For example In the Biology Test II, there are two items that concern human physiology most directly (items 2 and 15) and both of these concern heat regulation. It is not clear why such a focused set of questions was used. In my opinion, a more comprehensive measure of student achievement in human biology could have been obtained by constructing questions that assess understanding of how major body systems interact. Moreover, with proper construction of distractors, information could have been gathered (albeit limited) on major misconceptions students hold about the overall functioning of the human body based on a systems perspective. One item on nutrition (item 1) may be considered both a human biology and a molecular biology question. Unfortunately, the paucity of questions and the rather focused content will make it difficult to make strong conclusions about current student achievement in human biology. Clearly, however, the test appears to have been constructed to assess overall biology achievement, and therefore finer statistical analyses, as mentioned previously in the discussion of "subtest" reliabilities, will not be possible. Item 18 may be confusing owing to wording. The stem of the item states "What initially determines whether a human baby is going to be a male or a female?" While technically correct, the use of "initially" may confuse some tenth grade students who have reading difficulty and do not understand the temporal referent. This is only a conjecture as no empirical evidence is available to render a judgement.

One item included in both Biology Test I and II (item 14 for Test I, and item 17 for Test II) is unfortunately not technically correct based on current biological knowledge. This item states "Which one of the following processes in plants is not controlled by hormones?" The designated correct option is "A. water uplift in the stem." However, there is good evidence that abscisic acid, a plant regulator substance or "hormone," controls leaf stomatal closure under extreme water stress, thus limiting transpiration[8,9]. This finer technical point is not likely to be covered in secondary school biology, making the option at least appropriate for this age group. But, the misconception that is reinforced is unfortunate. The item could have been made technically more sound by rewording as follows: "Which one of the following processes in plants is least likely to be controlled by hormones?"

With respect to bridge items spanning both the biology tests, it is unfortunate that item 12 (Biology Test I) concerning food web dynamics was not included in the Biology Test II in 1986. This would have been a useful item to examine effects of maturation and schooling on understanding of system dynamics. It was included in the 1983 test for subgroup 3P and therefore provides some basis for comparison across grade level. However, this comparison is contaminated by the fact that the 3P students are enrolled in Physics and may possess very different intellectual abilities, educational history, and information processing skills than a more comparable 3B group. Item 15 (Biology Test II) is a good one for fine discrimination among the distractors, but may also be confusing for a poor reader. The first distractor attributing heat distribution round the body to blood circulation may be misinterpreted to be correct, since it is known that the distribution of blood in the body relative to surface versus deep organs does vary with temperature of the body surface, etc. Nonetheless, the item is likely to be a good discrminating question as indicated by the number of students who incorrectly chose item A (58.9% of all respondents), while only 27.3% chose the correct option.

On the whole, the items appear to be well balanced among basic knowledge and process-skills, and vary in content difficulty from specific-factual kinds of information to systemic and theoretical analytical questions. Additional interpretations are made in Chapters Five and Six.

Data From Other Instruments

A summary of the questions, and report of student responses to the individual items, in the Student Questionnaires for the Biology I and Biology II Populations is presented in Appendices C and D, respectively. The corresponding Mathematics Test items for these two populations are presented in Appendices E and F respectively.

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Chapter Five
RESULTS OF THE SECOND I E A STUDY: BIOLOGY ACHIEVEMENT

Major Findings

The results from Biology Content Tests I and II are presented in Tables 5.1 and 5.2 respectively[1]. The percentage of all respondents who scored correctly on each item is reported in bold face type, followed by percentiles for each distractor. The mean scores on both tests are low. The mean for Biology Test I is 12.8 (42.7% of all items) with s.d.. = 5.0, and for Biology Test II is 12.7 (42.5%), s.d. = 5.0. Among the 18 items common to both tests, the mean score on Biology Test I is 6.6 (36.7%), s.d. = 3.1; and for Biology Test II is 8.4 (46.8%), s.d. = 3.7. The test items for Biology Test I and II are displayed in Appendices A and B. As background information, summaries of responses to the student questionnaires (Populations I and II) are presented in Appendices C and D.

Further analyses of Biology Test results are presented in Figs. 5.1 and 5.2 placed on pages 68 and 69 to reduce interruption of the text. In Fig. 5.1, the items have been categorized by content areas. The purpose of this display is to permit rapid assessment of individual items within a given content area. It is not recommended that the histogram be used to make comparisons among the categories as we do not know to what extent the items are of comparable difficulty. In Fig. 5.2, the items are displayed by percentile in descending order. The main analyses reported here are for Biology Test I. Item 9 has the highest percentile (classified as an experimental design question) with 83% responding correctly. On a majority of the questions, less than 50% of the students responded correctly. Items 23 and 30 were among the lowest. Item 23 is a genetics problem that requires skill in predicting the phenotype of a F_2 generation based on knowledge of the parent's genotype. Item 30 asks the respondent to select the graph that best represents human population growth. With respect to the process items included in the data interpretation subcategory, item 28 is a complex question involving experimental instrumental design. The percentage of correct responses was 56.5%. Given the heterogeneity of students in basic biology courses at the secondary level, particularly given the proportion that are likely to be committed to science as a career, it appears encouraging that over half the respondents were able to analyze the apparatus and make a correct response. Likewise, it is interesting to note that on items 7 and 8 of Biology Test I, that are classified as process items in quadrant III of the Literacy Model, the percentiles were relatively large 66.2 and 67.3, respectively. From this author's perspective, these items represent more complex kinds of biological knowledge and skills. Item 9 in Biology Test I, classified as a process item in quadrant II of the Scientific Literacy

Model was answered correctly by 83% of the respondents. Item 12, categorized as a process item in quadrant III, involves a systems analysis of trophic interactions and was answered correctly by 28.8% of the respondents. As discussed more fully in Chapter Six, this rather low value may indicate a need for increased emphasis on systems learning in biology.

Table 5.1 Item Statistics for Biology Test I

Item	Type	Quad.	Percentile Total	Percentile F	Percentile M	A.	B.	C.	D.	E.
1	NP	I	**43.4**	45.5	41.5	26.7	10.5	11.8	7.1	43.4*
2	NP	I	**54.4**	51.1	58.6	54.4*	2.1	0.6	19.8	22.9
3+	NP	I	**46.5**	42.5	51.3	8.3	20.6	46.5*	9.8	13.1
4	P	II	**70.5**	66.4	74.3	3.1	6.7	5.6	70.5*	13.7
5	NP	I	**39.4**	36.7	42.9	39.4*	14.6	9.6	16.4	19.0
6	P	II	**48.6**	44.5	53.7	48.6*	2.5	2.6	2.4	43.8
7	P	III	**66.2**	65.0	66.9	10.9	66.2*	7.0	0.9	14.7
8	P	III	**67.3**	67.9	67.2	67.3*	5.6	6.6	18.3	1.4
9	P	II	**83.0**	85.6	79.3	5.0	83.0*	6.2	3.3	1.9
10	P	II	**49.5**	49.5	49.3	2.8	30.7	10.5	49.5*	6.1
11	NP	I	**40.3**	37.6	43.6	10.9	13.8	40.3*	29.8	5.0
12	P	III	**28.8**	22.4	37.6	20.2	7.1	8.1	28.8*	35.0
13	NP	I	**48.6**	45.7	51.4	48.6*	11.4	22.9	3.4	13.2
14+	NP	I	**29.3**	27.2	31.7	29.3*	9.8	16.6	30.4	12.5
15	NP	I	**27.3**	27.9	26.7	58.9	27.3*	9.1	1.3	2.8
16+	NP	I	**51.7**	54.7	49.4	2.5	15.0	51.7*	6.4	22.8
17	NP	I	**29.2**	26.5	32.8	3.1	22.8	29.2*	33.3	11.0
18	NP	I	**31.8**	31.2	32.4	31.8*	5.5	8.7	3.6	49.7
19+	NP	II	**44.9**	44.6	45.5	44.9*	18.4	17.7	6.6	11.0
20	P	II	**32.8**	27.0	40.1	6.6	9.6	32.8*	21.3	28.7
21	NP	I	**20.7**	19.0	22.4	39.2	21.5	2.6	20.7*	15.5
22	NP	II	**37.0**	37.3	37.3	30.2	37.0*	8.7	16.3	6.8
23+	NP	II	**22.4**	22.5	22.3	33.4	6.9	15.7	20.2	22.4*
24+	NP	II	**34.7**	35.2	34.4	13.7	34.7*	16.5	25.5	7.8
25+	NP	II	**37.1**	37.3	37.8	10.5	32.8	37.1*	11.5	6.5
26+	NP	I	**46.9**	45.7	48.3	13.4	46.9*	11.3	10.7	16.5
27+	NP	I	**46.5**	49.0	43.6	23.4	11.6	46.5*	11.9	5.1
28	P	II-III	**56.5**	53.6	60.3	56.5*	13.1	8.4	6.5	14.5
29+	NP	II	**28.0**	30.2	25.6	19.3	31.0	13.8	28.0*	6.8
30	P	II	**18.0**	11.2	25.9	18.0*	25.7	4.2	8.6	42.5

Note: P = Process item, NP = non-process item, Quad. is the quadrant categorization for the item relative to the two-dimensional Scientific Literacy Model (Fig. 1.1). However, within each of the higher quadrants II and III, few of the items would be categorized in the highest levels of these quadrants. F = female, and M = male. Bold entries are total percentage of students correctly answering the item. Columns A, B, C, D, and E. are percentages of respondents selecting each distractor. Asterisk = Correct option. Items marked + have 1 to 2% omitted responses by testees, remaining items are 1% or less.

Table 5.2 Item Statistics for Biology Test II

Item	Type	Quad.	Percentile Total	Percentile F	Percentile M	A.	B.	C.	D.	E.
1	NP	I	**42.1**	36.0	49.9	0.9	18.4	42.1*	29.5	9.2
2	NP	I	**48.5**	47.6	49.1	48.5*	5.7	9.5	2.7	33.2
3	NP	I	**32.1**	29.0	36.8	41.6	13.6	1.3	32.1*	11.0
4	NP	II	**44.2**	43.4	44.9	32.2	44.2*	5.8	12.5	5.0
5+	NP	I	**47.4**	47.0	48.9	27.5	9.9	47.4*	10.0	3.3
6	NP	II	**26.9**	27.9	26.2	18.2	26.9*	23.2	14.5	16.8
7+	NP	II	**31.2**	30.3	30.7	27.7	5.5	17.0	17.4	31.2*
8	NP	II	**38.7**	39.0	37.2	16.5	38.7*	11.3	25.2	5.8
9+	NP	II	**43.2**	41.6	45.7	12.3	29.5	43.2*	8.6	5.0
10	NP	I	**59.7**	55.4	65.8	59.7*	7.1	20.4	4.2	8.3
11	NP	I	**18.3**	16.3	20.5	18.3*	18.3	13.9	11.0	36.9
12+	P	II	**32.7**	26.1	40.8	6.7	32.7*	31.7	2.1	24.4
13	NP	I	**27.5**	26.0	28.9	14.7	7.0	14.4	27.5*	34.8
14	P	III	**52.8**	51.0	55.9	29.3	2.6	52.8*	7.7	7.0
15	NP	II	**36.7**	36.6	35.7	39.6	10.8	36.7*	6.9	4.5
16	NP	II	**27.5**	28.7	24.6	7.3	34.1	1.9	27.5*	28.4
17	NP	I	**37.2**	33.4	41.6	37.2*	8.7	13.7	28.6	10.7
18+	NP	I	**27.4**	25.9	29.2	20.4	13.6	16.0	27.4*	18.8
19+	P	II	**70.5**	70.0	72.3	13.0	5.5	70.5*	4.5	4.8
20	P	II	**52.6**	53.8	51.1	14.5	24.0	4.5	3.6	52.6*
21	NP	I	**57.7**	55.4	61.5	8.6	57.7*	7.7	5.8	19.4
22	P	II	**69.1**	65.9	72.8	2.7	15.0	8.8	69.1*	4.2
23	NP	II	**34.4**	32.9	36.3	13.0	37.7	8.4	34.4*	5.8
24	NP	I	**58.2**	53.7	62.8	4.9	8.3	58.2*	22.4	5.8
25	P	II	**45.2**	39.5	53.2	4.7	6.8	45.2*	14.8	26.6
26+	P	II-III	**68.7**	63.8	74.7	68.7*	10.4	5.2	4.1	10.3
27	NP	I	**60.4**	60.2	61.7	2.2	11.5	60.4*	3.7	21.2
28	NP	II	**12.3**	7.7	17.6	2.0	70.0	12.3*	8.1	6.6
29+	NP	II	**45.9**	43.1	50.7*	45.9	16.3	15.7	6.8	13.8
30	P	II	**25.2**	19.0	34.2	25.2*	17.9	1.9	8.9	45.3

Note: P = Process item, NP = non-process item, Quad. is the quadrant categorization for the item relative to the two-dimensional Scientific Literacy Model (Fig. 1.1). However, within each of the higher quadrants II and III, few of the items would be categorized in the highest levels of these quadrants. F = female, and M = male. Bold entries are total percentages of respondents answering the item correctly. Columns A, B, C, D, and E. are percentages of respondents selecting each distractor. Asterisks = correct option. Items marked with a + are those with 1 to 3% omitted responses by testees, all remaining items are less.

Table 5.3 Comparative Data for Female and Male Respondents on Categorized Items: Biology Test I and II

	Biology Test I				Biology Test II		
	% Responding Correctly				% Responding Correctly		
Category	F	M	Total	Category	F	M	Total
Cellular 5, 13, 17, 22	36.6	41.1	38.6	Cellular 1, 4, 10	44.9	53.5	48.7
Plant 3, 14, 27	39.6	42.2	40.8	Plant 5, 13, 17	35.5	39.8	37.4
Animal 1, 2, 11, 15, 21, 26, 30	34.0	38.1	35.9	Animal 3, 11, 14 - 16, 18, 21, 24, 30	35.1	40.1	37.3
Ecology 4, 7, 8, 12	55.4	61.5	58.2	Ecology None	-	-	-
Evolution 16, 19, 29	43.2	40.0	41.5	Evolution 23, 27 - 29	36.0	41.6	38.3
Genetics 18, 23 - 25	31.6	31.7	31.5	Genetics 2, 6, 7 - 9	37.3	37.8	37.7
Data Interp. 6, 9, 10, 28	52.0	56.5	54.1	Data Interp. 12, 19, 20, 22, 25, 26	53.2	60.8	56.5
Total Scores	41.4	44.5	42.7		40.2	45.4	42.5

Comparative Data

The comparative performance of male versus female students is summarized in Table 5.3 by content subcategories. In general, the percentage of females responding correctly was less than for males, except for items on genetics. With respect to total score, for Biology Test I, the percent of males responding correctly was 44.5% and for females, 41.4%. For Biology Test II, the percent of males scoring correctly was 45.4% and for females, 40.2%. In terms of mean score, on Biology Test I, the score for females was 12.4 and for males 13.3 ($t = 4.70$, $p << 0.01$), and for Biology Test II, the score for females was 12.1 and for males 13.6 ($t = 3.91$, $p << 0.01$). This rather consistent difference points toward a continuing dilemma of the need to encourage greater scientific achievement among female students. Some of the socio-cultural and educational implications of this issue have been presented by Humrich[2].

In general, across all grade levels and for all subject areas of science tested, the mean score of females is less than males. Although this trend is also reflected in performance on most questions of the biology tests, there are some exceptions where performance is equal or nearly equal. In Biology Test I, items 7, 8, 15, 16, and 23 show nearly equivalent performance; while, items 9 and 24 show a slightly enhanced performance by female students. Some of these items, though not exclusively, require higher level thought processes or include problems with complex interactions among variables. This may suggest that female students are particularly at par with male students or even slightly advantaged with "non-mechanical" kinds of problems requiring increasing amounts of formal thought. Very limited evidence from this test suggests that female students may do as well as, if not better than, males on genetics problems.

International Findings

Only the data from Biology Test II are used in this analysis since the respondents are comparable in age to respondents in other nations[3]. Moreover, only 25 of the items in Biology Test II were the same across all nations. The United States mean is 16.5. It is among the lowest in the list, next to the last. The range of scores is 11.5 to 21.7. These data must be interpreted with the knowledge that the United States sample size was very limited. Only 659 students were tested, and this raises serious questions whether such a small sample from 43 schools is representative of the nation. This is in contrast to 2,582 students from 118 schools who responded to Biology Test I. There are no comparative international data for the latter population since there are no comparable groups in the international sample. No further international comparisons will be made in this report. Further comparative details of performance for the advanced science groups (Populations 3C, 3B, and 3P) are presented by Ferko[4].

Relationships Among Biology Test Scores, Mathematics Tests, and Word Knowledge

A rather strong correlation was found between Biology Test scores and Mathematics Test scores. For group I, where the size of the sample is deemed sufficiently representative, $r = 0.5$ ($p \ll 0.01$). However, some of this covariation may be explained by a common contributing variable of cognitive ability (i.e. intelligence or information processing ability). Thus, in general we would expect that the student who is more able cognitively will perform better on both the mathematics test and the biology test, producing a strong correlation between the math and biology scores . Hence, the correlation may not reflect a direct linkage between the student's mathematics ability and the set of biology items presented in the test, but rather reflects common variation that is accounted for by a third variable, i.e. cognitive ability. In the absence of a standard intellectual ability measure, the word knowledge test scores were used as a predictor in a partial correlation analysis to determine how much of the variance in biology test results could be accounted for by the mathematics test scores when word knowledge was taken into account. The partial correlation coefficient was $r = 0.44$ ($p<<0.01$). It is sufficiently strong to suggest that mathematics skills assessed by the Mathematics Test are contributing to some of the variance in the biology test scores. This is reasonable as some of the items clearly require quantitative skills.

Other Findings

The responses to the Student Questionnaire for group I and group II are summarized in Appendices C and D as background information to aid the reader in interpreting the overall student perceptions of the socio-cultural and school environmental variables that formed the context for this survey. Correlations between the questionnaire or opinionnaire items and student achievement assessed by the Biology Content Tests produced very low coefficients with a few in the 0.2 range. Given the uncertainty in precision of the background data instruments and the lack of sufficient control for other contributing variables that may account for some of the correlations found in this survey data, no further statistical interpretations appear to be warranted. Additional information, however, may be extracted if the data are grouped into larger categories, and a factor analysis could provide some preliminary insight toward this goal. In the student opinionnaire items, the options were "Often, Sometimes, Never." The low resolution provided by these three options and the lack of any means of calibrating the responses to know whether one respondent's use of often is equivalent to another's use, among other limiting factors, does not permit further inferential statistical analyses of these data. The data may be of interest as evidence of some general opinions expressed by the students in the sample, but these data will not be included in this report.

Descriptive Analyses of Biology Achievement Among Schools

As a general aid in interpreting the range of performance among students across schools, the mean score on Biology Test I is presented for schools falling within each decile (Table 5.4). This breakdown of the data may provide further insight into differences across schools, that in the United States are highly diverse, and gives some finer resolution to the question of how well students in the best schools perform compared to those in the schools with the lowest mean scores. The mean score for schools in the highest decile is 18.3 out of a total of 30 test items. The mean score for schools in the lowest decile is 7.8. As a further perspective on variations in responses among schools, responses of students in the schools within the highest decile are compared to those from schools in the lowest decile. Only some items are chosen to illustrate variations. Item 5 in Biology Test I is a non-process type question and requires the respondent to identify which cell diagram among 5 types is found in the human nervous system. Among the schools in the highest decile, 67% of the students were able to correctly identify the diagram of a neuron as the correct response. For the respondents in the lowest decile group, 15.1% made the correct identification.

Table 5.4 Decile Distribution of Biology Test I Mean Scores Among Schools

Deciles	1	2	3	4	5	6	7	8	9	10
Biol. Test Means	7.8	9.5	10.6	11.5	12.4	12.9	13.8	14.8	15.8	18.3
Mean Class Size	18.0	20.0	25.0	23.0	23.0	25.0	26.0	24.0	22.0	22.0

Interestingly, a diagram of a plant cell was included among the distractors in the array of animal cells, and 25% of the students among schools in the lowest decile chose this option, while 6.9% of these students in the highest decile chose this distractor. Item 2 concerns "The main way that sweating helps the body." In the lowest decile, 19.6% of the respondents correctly identified cooling as a main role of sweating, while 79.9% of the respondents in the highest decile chose this response. Among the distractors that were selected most frequently, elimination of salt was marked by 35.9% in the lowest decile and 11.1% in the highest. Elimination of excess water was chosen by 41.3% in the lowest decile and 9.0% in the highest decile. Both of these questions are categorized as non-process and assigned to quadrant I of the Literacy Model. Five process-type items are also analyzed in the same way. Item 6 presents a graph to be interpreted. Among the respondents in the lowest decile, 24.9% answered correctly while in the highest decile 70% answered correctly. The option "One cannot tell from the information" was chosen by 58% in the lowest decile and 2.5% in the highest decile.

Item 8 displays a diagram of aquatic organisms with arrows showing the flow of substances labelled a or b. Among the respondents in the lowest decile, 50.5% answered correctly, i.e. oxygen is produced by plants and carbon dioxide is produced by animals.

Interestingly 26.6% chose the distractor that is completely opposite, i.e. plants produce carbon dioxide and animals produce oxygen. Among respondents in the highest decile, 87.5% responded correctly, and only 9.6% chose the "opposite" distractor. Item 10 requires interpretation of trends in tabular data. Among the respondents in the lowest decile, 23.6% correctly identified the proper correlation between protein concentration and the rate of growth of the offspring. 35.1% chose the distractor "The greater the protein concentration in the mammal's milk the slower the newborn baby will double its weight." By comparison, in the highest decile, 77.3% responded correctly and 15.2% chose the correspondingly incorrect distractor relating size to milk composition. Item 12 displays a food web. In the lowest decile, 4.13% correctly identified that decline of a predator one step removed from a prey would produce an increase in the intermediate predator population and thus decrease the numbers of the prey. In the highest decile, 57.2% answered correctly. One of the most common false distractors chosen was that the prey would increase. In the lowest decile, 15.5% chose this distractor while in the highest decile this distractor was chosen by 17.6% of the respondents. The final item analyzed here is 28. This presents a diagram of an experimental apparatus on respiration and asks for an interpretation of changes in volume of the respiration chamber. Among respondents in the lowest decile, 30% correctly identified that a smaller container would provide a means of getting the "Quickest" results from the apparatus. In the highest decile, 80.4% made the correct response. For both groups, responses were largely scattered among the remaining distractors.

On the whole, even in the highest decile group, the responses of the students are not particularly strong for some items. This is especially true for what appears to be a very basic question such as item 6 requiring recognition of a neuron among other highly diverse cell types. Indeed, the common error of identifying a plant cell as the correct choice is all the more disturbing since a later question clearly labels such a cell as a plant cell. As it happens, an additional test item contains a similar picture of a plant cell clearly identified as belonging to a plant, yet this information appears not to have been used by many of the students to correct their response to the neuron question. The fact that the informative test item comes at a later point in the test booklet may reflect, among other possibilities, that the respondents who incorrectly chose the plant cell distractor did not either recall it or did not go back to correct the response even if they subsequently understood their error.

In summary view, these results are somewhat disappointing, particularly from a general perspective that the test items do not appear to be unusually demanding for secondary school students given the level of information presented in textbooks for "first-year biology" and in relation to general expectations of what our "best schools" should be able to produce.

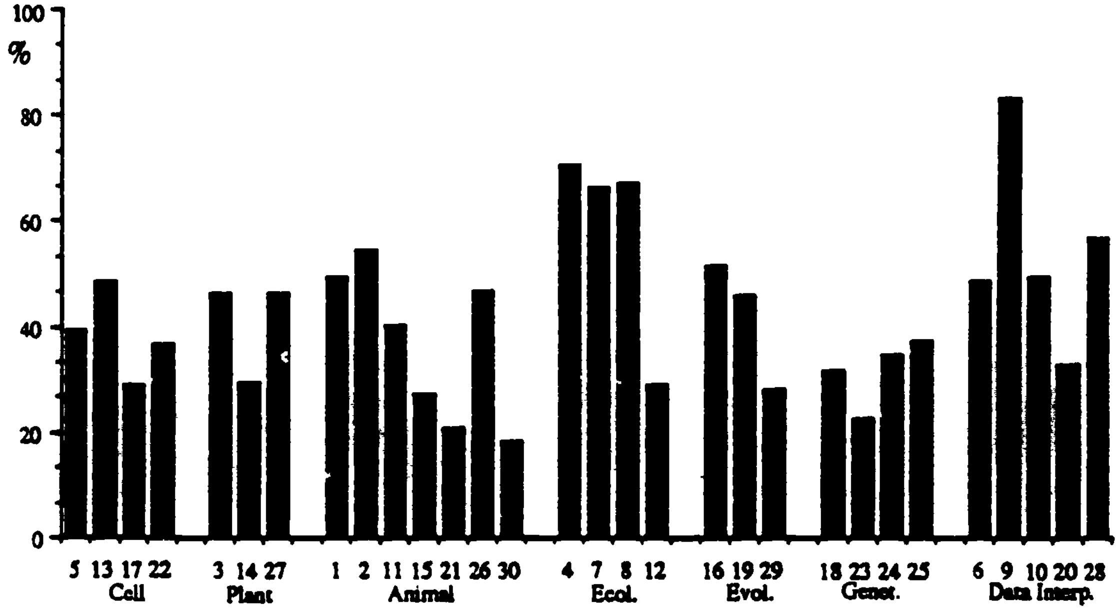

Figure 5.1a Histogram: Item percentile distribution grouped according to subcategories. Biology Test I.

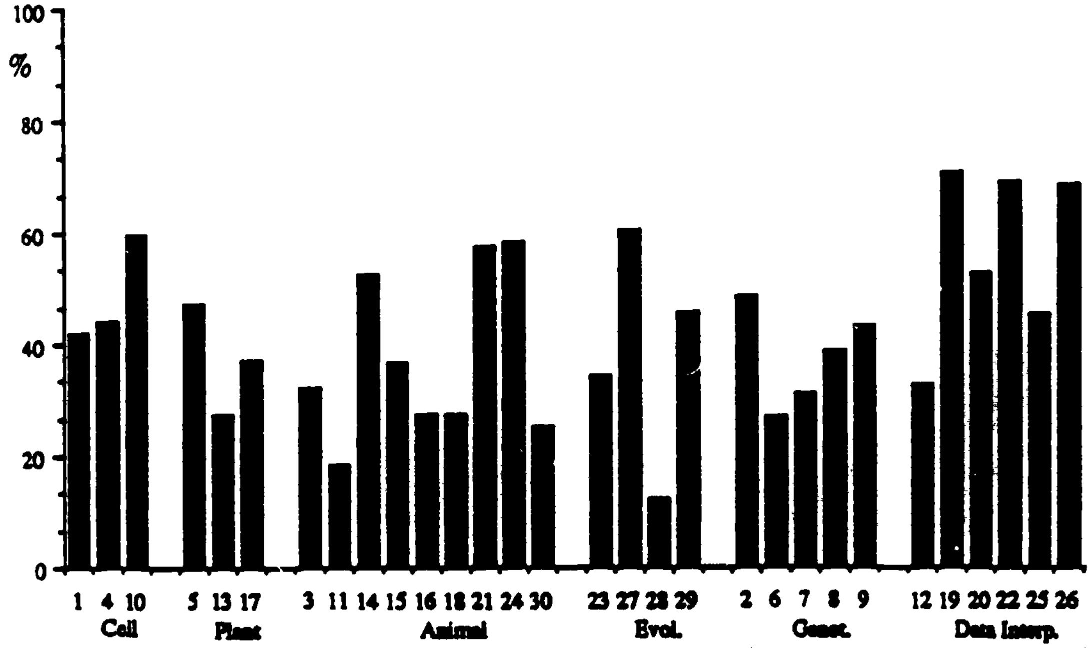

Figure 5.1b Histogram: Item percentile distribution grouped according to subcategories. Biology Test II

Note: The assignment of items to content subcategories is intended only as an aid in identifying individual test items of similar biological content. It is not recommended that comparisons be made between groups or among items in a group since we do not know if they are of comparable difficulty. The histogram plot gives approximate values for the percentiles, refer to Tables 5.1 and 5.2 for more exact numerical values for the percentiles.

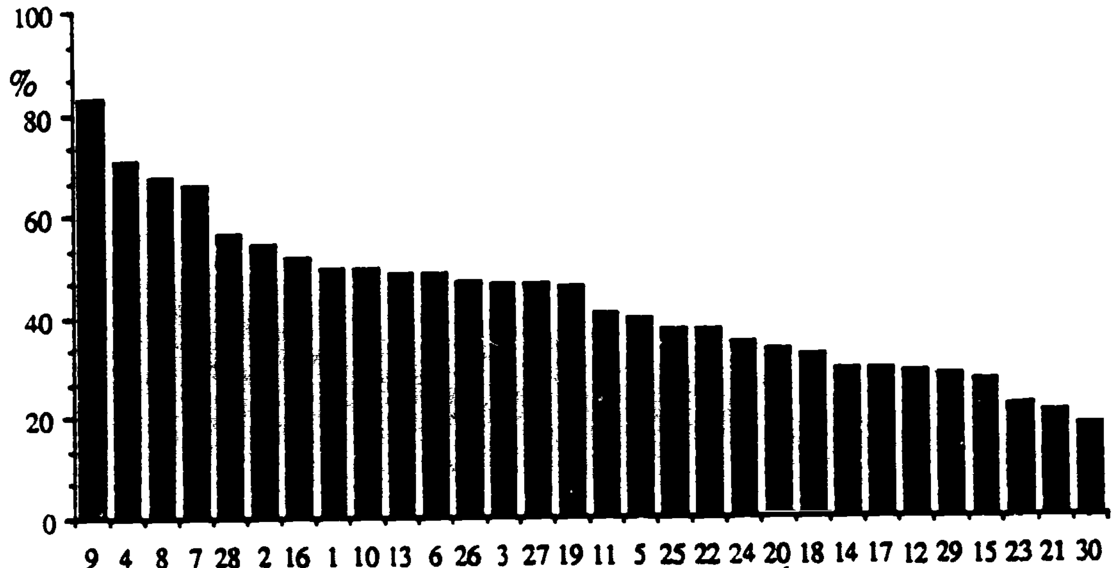

Figure 5.2a Histogram: Item percentile distribution in descending order. Biology Test I.

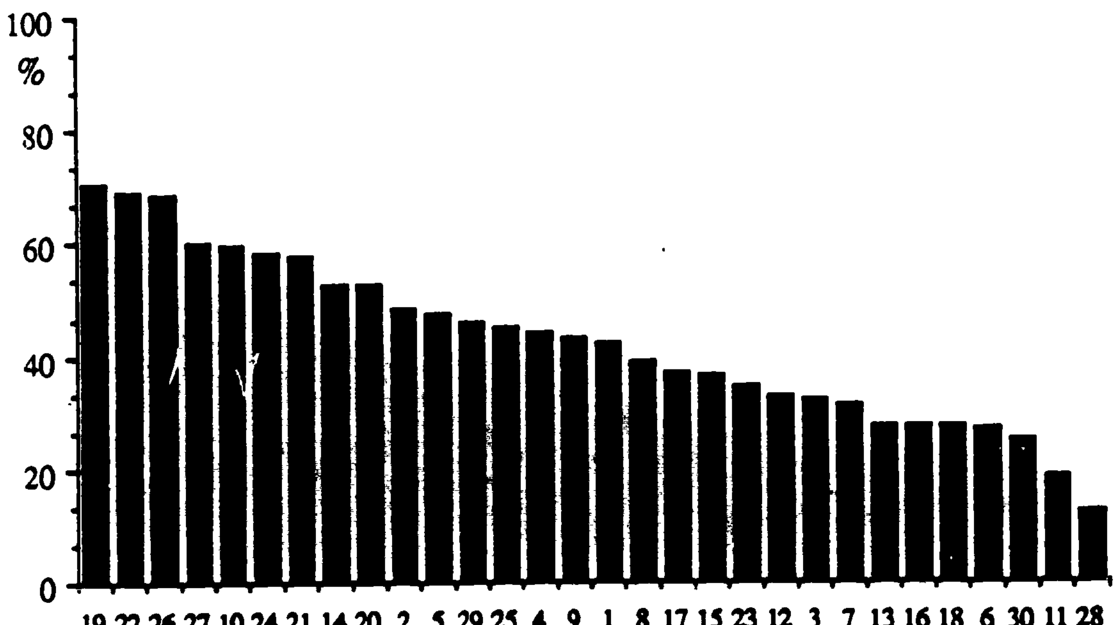

Figure 5.2b Histogram: Item percentile distribution in descending order. Biology Test II.

References

1. Appendices A and B contain reproductions of Biology Test I and Biology Test II, respectively.

   Additional findings of the SISS can be found in a report published by

   W. J. Jacobson and R. B. Doran, *Science Education in the United States: A Report to the Public.* Second International Association for the Evaluation of Educational Achievement Monograph. Washington, D.C.: National Science Teachers Association. 1988.

2. E. Humrich, *Sex and Achievement in Science.* Second International Association for the Evaluation of Educational Achievement Monograph. New York: Columbia University, Teachers College. 1988.

3. International Association for the Evaluation of Educational Achievement, *Science Achievement in Seventeen Countries: A Preliminary Report.* Oxford: Pergamon Press. 1988.

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Chapter Six
CONCLUSIONS

General Findings

Within the scope and range of difficulty of the items contained in the Biology I and Biology II tests administered to the sample of American students, the results of the SISS survey are not encouraging. The generally poor performance of the students on the 25 common items contained in the tests administered internationally, and the generally low percentage of respondents who correctly answered items containing very fundamental biological knowledge, raises serious questions about the academic preparation of many of our students in secondary school biology. This point has also been addressed in the report summarizing the United States results of the SISS: "The achievement of advanced science students in biology, chemistry, and physics is low. The biology results are especially low. For a technologically advanced country, it would appear that a reexamination of how science is presented and studied is required[1]". Although the international comparative data can be criticized on the grounds that the American sample was small (N = 630 from 43 schools), and therefore may not be representative of all the students, given the diversity of American secondary schools; the poor performance of the Biology I Population is less easily qualified. This sample of 2,582 students, though only a small percentage of the total secondary school biology population, appears to be well documented as a representative sample of American secondary school students. The mean score for this group (30 items) was 12.8. Only 42.5% of the items were correctly answered. For the Biology II population, the mean (30 items) is 12.7 or 42.5% correct. The poor performance is also reflected in the number of students who could not correctly respond to questions dealing with very fundamental biological information. This includes among other examples, that only 20% of the respondents in Biology I Population could identify where a human egg is fertilized, and that 29.2% properly recognized that during the process of mitosis, the number of chromosomes in the nucleus remains unchanged. Likewise, 37% of the respondents in the first-year biology group identified correctly a cell with a solute concentration producing a net inward diffusion of water. In a diagram showing aquatic organisms, 67.3% correctly identified the animals as a source of carbon dioxide and the plants as a source of oxygen, while as much as 18% chose the opposite relationship. Performance on genetics problems, as found in other studies cited in Chapter Three, was uniformly low. In the Biology I test population, 22.4% of the students correctly selected the proportion of offspring produced in an F_2 generation (item 23). For a problem involving two traits (item 25) 37.1% properly selected the proportion of offspring with the expected phenotype.

The comparative performance of the students on the 19 anchor items in Biology Test I and Biology Test II is also disappointing. The first year biology population achieved a mean score of 6.6% compared to a mean of 8.4% for the Biology II group. However, certain items showed a clear increase. For example, Biology I-10 concerning interpretation of scientific tabular data was correctly answered by 49.5% of population I, while 69.1% of respondents in population II correctly answered the question. With respect to the conservation of chromosomal number during mitosis (item 17 Biology Test I), 29.2% of the first-year biology group answered correctly, while 42.1% of the advanced biology students chose the correct distractor. While the increases are satisfying, the rather poor overall performance on this item and others remains a disturbing factor. It is difficult to accept that less than half of second year biology students appear to understand the principle that chromosome number remains constant during the process of mitosis. Approximately 31% of the population I students correctly identified DNA in the sperm as determining whether an offspring will be a female or a male, while 48.5% of the advanced biology students responded correctly. There was a negligible difference on an item requiring interpretation of zoogeographic data pertaining to speciation. Approximately 45% answered correctly in first-year biology sample while 45.9% answered correctly in the advanced biology sample. There was some increase in correct responses on the common genetics items. For example on the item requiring predictions based on two traits (item 25 of Biology Test I), 37.1% answered correctly in the first-year biology sample while 43.2% answered correctly in the advanced biology group. For the item requiring prediction of proportions of individuals in an F_2 generation (item 23, Biology Test I) 22.4% responded correctly in the first-year biology sample, while 31.2% responded correctly in the advanced biology group.

It is encouraging to note, moreover that on one scientific process item (number 9) in Biology Test I, 83% of the respondents properly identified the conditions that satisfied a controlled experiment. Likewise, 70.5% of the Biology Test I respondents correctly identified the evidence that would allow someone to identify a carnivore based only on skull skeletal evidence (item 4). In the advanced biology group, 70.5% of the respondents correctly identified a valid conclusion implied by evidence from a procedure used to determine transpiration rate in plants (item 19, Biology Test II).

In the beginning and advanced biology groups, female students' scores were lower than those of male students, with the exception of a few items. It appears increasingly clear that female students are not obtaining an equivalent educational experience compared to male students and more intensive research is needed to clarify the factors contributing to this difference.

In general, there is wide diversity in student scores among the schools sampled. This has been described more fully for the first-year biology sample in Chapter Five. There is little convincing evidence from the background data collected during the Second Science Study to explain this variability. None of the correlations were considered sufficiently large to make a sound inference as to what factors assessed by the questionnaires, and other instruments, might account for the variance in student scores. In part, this is not surprising since a much more detailed analysis of operations in a school are probably required to understand the many socio-cultural and psychological factors that may jointly contribute to variations in academic achievement in an educational setting. Given the lack of clear empirical evidence to account for the variations in performance within these sets of samples, it is not possible to make recommendations from these data that may assist school practitioners in improving scores on tests such as these. However, as an aid in furthering basic research to clarify these issues, and to help practitioners develop an informed position on curriculum reform in secondary school biological education, some comments are presented based on current literature and some results of the SISS study.

Some Perspectives On Secondary School Biology Curricula

General Biological Education and Scientific Literacy

There is little doubt that educators in American secondary schools are presented with a very difficult task in meeting the varied needs of their students. This is occasioned, among other factors, by the marked heterogeneity of student abilities, variations in financial and psychological support, and the wide range of subjects to be included in four years of schooling. In some cases factors contributing to variations in achievement are not directly under the control of educators (i.e. cultural and home-background variables, and amount and quality of homework) that are not easily altered by school experiences[2-4]. With respect to homework, the questionnaire data collected for Biology Populations I and II (Appendices C and D) show that 55% of the first-year biology students and 54% of the second-year biology students spent no more than 2 hours on biology homework each week. Approximately 25% of the respondents in both populations reported working more than 2 hours per week on science homework. The remaining proportions of students reported that no homework was assigned, or reported not doing homework. If so little homework is being done on the average by secondary school students, and assuming this pattern is not easily altered by the school, it becomes apparent that the school experiences must be carefully planned to be of the highest possible quality. Productive time on task, including sufficient in-depth instruction in scientific concepts and broad organizing ideas in the field, is clearly important to enhance achievement in secondary school biology. Careful attention needs to be directed to an appropriate balance between laboratory-based learning and more intensive knowledge-constructing, cognitive tasks that help the learner develop sound knowledge structures in the field.

The need for enhanced understanding of science as an intellectual enterprise and the clear necessity to introduce future citizens to a reasonably comprehensive knowledge of scientific principles and broad organizing ideas is often at variance with the dual role of the secondary school as a general education environment and a bridge into advanced learning at the college level. The broad range of prospective professional and intellectual interests of the secondary school biology population is reflected in the responses to the questionnaires administered by the SISS. It is probably not surprising that the responses to the questionnaires in the biology I population show that only 24% intended to take further courses in science or applied science, and ca. 25% reported intentions of taking business or social science courses. In the Biology II population, 40% plan additional science courses, and about 25% report plans to take courses in social science, business or language. The larger proportion interested in science courses in the biology II group is not surprising since this is an advanced course which may attract potential science majors. Sixty-three percent of the Biology I respondents plan to attend college compared to 78% in the Biology II group. It is clear, based on these questionnaire data, that even in the more advanced biology courses there is considerable heterogeneity in student interests and plans for further education. This places a heavy demand on the educational system to simultaneously serve several populations to include both higher order science experiences suitable for the science-oriented students as well as the fundamental literacy required by future citizens in other professions.

Moreover, as it becomes increasingly evident that many productive positions in modern society will be technologically based and require increasing expertise in science, it is necessary to provide a thorough grounding in science at the secondary school level to permit access to these positions. Professional mobility is much more common in modern society than previously. With increasing opportunities in scientifically-based positions, future citizens may find greater need for a sound scientific background to take advantage of new professional goals. However, with an increasing emphasis on scientific learning, we must not lose sight of the broader aims of the secondary school in educating individuals to be wise as well as informed. An education that creates a scientifically elite population without a clear understanding of their socio-cultural origins, philosophy of human progress, or commitment to community ideals is undoubtedly a shallow gain. Nonetheless, we are equally vulnerable to extinction if we fail to recognize that scientific acumen, informed by humane wisdom, is essential for survival of most modern social systems.

The need for a biologically literate society is among the most pressing demands of modern schooling. While not limited to breadth in scientific vocabulary, and certainly requiring understanding of science broadly as a process, it is clear that informed citizens should at least comprehend the significance of technological and scientific issues that are increasingly reported in the news media or in national surveys on science-related topics.

Few informed, modern science educators would advocate improved scientific literacy by rote memorization of arrays of apparently isolated scientific facts. Yet, it is increasingly clear that without some comprehension of conceptual frameworks, supported by a minimal understanding of subsumed specific scientific ideas, it is almost impossible for members of modern society to fully appreciate, or rationally comprehend, the major technical and cultural advances being realized. Literacy may be defined in many ways, and only one among several current concepts has been proposed here in Chapter One; but it is clear that some understanding of scientific vocabulary is essential to even the most rudimentary comprehension of public reports on current scientific progress. However, a vocabulary composed of list-like definitions of terminology is not only inefficiently learned, it has little transfer value in assisting the learner to comprehend and assimilate new forms of knowledge. A well organized conceptual understanding of scientific information forming a network of logically linked constructs can enhance the generative potential of information in memory[e.g.5]. In a balanced view, this does not imply that we should emphasize concepts and principles in science education to the exclusion of knowledge about specific facts. Although research has shown that individuals typically recall principles more effectively than factual information, it should not be forgotten that there is also a substantial psychological literature to show that once specific information has been acquired, future recall is enhanced upon rehearsal or re-exposure to the content. This "savings in relearning" is not a negligible factor when complex problems require rapid access to diverse kinds of information in reference sources. We do a disservice to our student clientele if we do not encourage them to master sufficient pertinent specific information to strengthen their conceptual understandings. Moreover, well integrated knowledge structures, containing conceptual and specific information ordered within hierarchical or network relations, serve as frameworks for future relearning and as a base for extension of scientific understandings. The Scientific Literacy Model presented in Chapter One, may provide some assistance in planning biology curricula to include higher level categories of scientific literacy within a well-ordered sequence of increasing maturity of ideas suitable to the cognitive development of the learner.

Both conceptual and specific learning is enhanced by integrating information within reasonably comprehensible knowledge structures and cognitive models of phenomena. Various instruments have been developed in recent years for this purpose including concept maps[6], hierarchical models, network or systems models and thematically based nested categories of knowledge[7]. Conceptual models of appropriate complexity and level of abstraction, or hierarchical systems for subsuming information in nested arrays are among the general organizing schemes that have been shown to aid meaningful information acquisition. For many secondary school students, who are not fully formal operational, the organization of information within clearly defined and explicitly referenced themes can enhance connected and meaningful learning.

Within this context, the issue of balance between "unstructured," self-directed learning and "more structured," teacher-directed interactive learning becomes evident. While few modern educators are likely to advocate teacher-dominated lectures as a means to efficiently improve scientific literacy at the secondary school level, it is also unlikely that continuous application of open-ended, sometimes less-structured, inquiry lessons can provide the necessary conceptual organizing aids that many secondary school students require. In the wake of increasing evidence of decreasing performance by our secondary school students, some reformers call for a national curriculum in the sciences. We need to carefully and critically consider the implications of this recommendation. On the one hand, a more coherent set of guidelines and recommended competencies to be achieved in biological education may be welcome. Indeed, some carefully prepared enrichment modules to help instructors expand their repertoire of strategies or other guides to carefully tested learning experiences may be helpful in enhancing the quality of American biological education. But, do we want to institute a rigid national curriculum that effectively dictates the course of instruction in all of our schools? In one respect, the BSCS curriculum was intended to be a national curriculum and is oft-times cited as a "Teacher-proof" curriculum. That is a curriculum that was supposed to be robust enough to overcome deficiencies in the instructor's competency. I think many would now agree that a concept of a "Teacher-proof" curriculum is faulty. The biology instructor is a key, if not the most significant, variable in determining the quality of biological education in our secondary schools. Do we want to remove most if not all of their power to make reasoned and professional decisions about the scope and sequence of content to be presented? Clearly, we all can benefit from guidelines for improvement of our professional services and ought to be encouraged to keep up with improved methods of instruction. But, do we make significant gains by imposing a rigidly prescribed national curriculum that may proscribe the creative and professionally informed judgements that we should expect our secondary school teachers to make?

One of our most valuable educational resources in our schools is the mature understanding that well-educated professional teachers bring to the learning environment. This includes skills in leading scientifically-based discussions as a means of improving the student's ability to think critically and reflectively about their strategies for drawing conclusions. In general, I suspect that our colleagues in the humanities have used discussion more extensively and with more thoughtful deliberation about its instructional significance than we have in the sciences. In large measure, the burden of student self-directed learning has largely been posited in laboratory experiences. Yet, these experiences often pass without time to reflect on what was done and why. The experience may be improved by some reflective, guided discussion as to the major concepts and principles forming the context for the experiences and the scientific reasoning processes employed. When as sometimes happens the experiments are not fully successful, a constructively critical evaluative assessment of the rationale for the experiment and its investigative procedures can be beneficial to aid the student in understanding the significance of the experience. Secondary school students, especially, can benefit from interactive dialogue in structured learning exchanges with teachers. Maturation in scientific literacy, especially progression toward competencies in Quadrant II and higher levels in the Science Literacy Model (Fig. 1.1) can be enhanced by content-focused discussion that encourages students to explain and evaluate their understanding of biology in broad interconceptual terms.

Early in the development of the BSCS curricula, the value of classroom focused discussion was emphasized. The development of the "Invitations to Enquiry" was intended to stimulate greater use of this technique in secondary school biology teaching. Schwab[8], identified three functions that a well organized discussion should accomplish:

"1. It should move toward an understanding of some specific item of knowledge.

2. it should move along logical lines that are consistent with the principles of [biological] investigation.

3. it should stimulate the student to participate in the activity that will lead to the understanding sought."

These recommendations were intended to help discussion leaders avoid the common pit fall of aimless or sometimes bellicose exchanges that can occur among discussants. The second recommendation suggests that the discussion leader assist the group in identifying specific problems or hypotheses to be discussed usually in relation to an experiment the group has read about, observed in a film, or preferably done in the laboratory. This problem area is then carefully explored by seeking scientific evidence, discrminating empirical evidence from opinion, applying consistent and defensible criteria in making judgements, and clarifying differences in conclusions if consensus is not reached. On the whole, the mature reasoning ability of the teacher is essential as a catalyst to sustain directed discussion and to serve as a model of how scientists think.

This also includes the use of properly organized and prudently distributed expository presentations by the teacher to clearly illustrate how a mature and logically-organized individual perceives the broad conceptual schemes in a discipline. However, over reliance on teacher monologue with little opportunity for students to formulate their own responses to the issues presented, or to create critical judgements about what they are learning, is also not likely to be productive. Clearly organized presentations that alternate teacher exposition with episodes of interaction requiring student discussion and exchange of ideas around higher level thought questions and within problem-solving contexts may be a useful adjunct to inquiry-based learning experiences. These learning experiences may be enhanced by giving careful thought to the design of the presentation so that organizing themes are made explicit. Student contributions may be recursively woven into the presentation by linking them to the explicit theme idea or asking students to summarize their contributions by subsuming them within the conceptual idea or scientific principle constituting the theme. The more intellectually able student may also be better served by arranging instruction such that the students are challenged early on in a learning experience to deduce the theme of a presentation and/ or to suggest ways of further developing the theme. It is clear that the use of explicit themes in ordering information, while assisting the intellectually less-able student, may also deprive intellectually gifted students from realizing their full educational potential. We need additional practical research initiatives to determine how best to create a sufficiently intellectually stimulating learning experience to permit the academically advanced student to excel, while also providing for the more structured and teacher intensive interaction needed by the less academically able student. Diversity in approaches to teaching that permit students of different backgrounds to benefit from structured learning is clearly admirable.

While we have considerable theory to suggest that use of varied patterns of structured and unstructured learning is likely to enhance acquisition of stable and extensible knowledge structures, we need much more research on this topic to determine what mix is best for students of varying mental maturity and in relation to content of varying abstractness. Experimental studies, while traditionally a major source of information on improvement of teaching strategies, can be augmented by ethnographic and interview techniques to determ which creative teaching strategies employed by master teachers contribute to highest s nt gains.

Though there is insufficient evidence to clearly explain the poor test performance of American students in first and second year biology of the SISS study, and it is likely that many cultural factors including the role of community and family variables that affect learning are involved, we need to carefully assess current biology teaching strategies to determine how to improve student comprehension of basic scientific facts, concepts, principles and theories in the field. The test results suggest that students not only responded poorly to specific factual items, but also are unable to utilize systems theory and other conceptual organizing aids in interpreting biological phenomena. Poor performance on items requiring interpretation of graphs, proportional reasoning, and quantitative problem solving also suggests that there is a need for more sustained attention to developing these skills.

Student Conceptions and Misconceptions

Within the limits of the distractors in the items of the SISS test, it is possible to analyze some of the conceptions and misconceptions of this sample of students. An examination of some of the distractors selected by large numbers of the respondents provides some clue to their understandings. Of course, it is not easy to separate sheer guessing from deliberate selection, but if a distractor is consistently chosen by a large percentage of the respondents, it suggests a more deliberate decision.

Some examples will be presented based on the type of content. Additional examples of incorrect options have also been presented but not fully discussed in Chapter Five. Most of the examples will be drawn from the first-year biology group. Comparisons with the advanced biology group will be specified. The generally poor performance of students in differentiating plant cells from animal cells (e.g. item 5, Appendix A), suggests that greater emphasis needs to be placed on observation skills and knowledge of visual discriminators. As much as 23% of the respondents thought cellulose, not protein, was found in all cells, while 13.2% chose hemoglobin (item 13, Appendix A). By comparison, in the advanced biology group, 20.4% chose cellulose, and 8.3% chose hemoglobin. Thirty-three percent of the respondents thought that the number of chromosomes doubled in the daughter cells after mitosis. This misconception may arise from a failure to discriminate between chromosome doubling in preparation for cytokinesis, versus the separation of chromosomes during anaphase leading to conservation of chromosome number in the daughter cells. On a cell physiology problem, 30% thought water would diffuse from a region of higher solute concentration to a region of lesser solute concentration. Likewise in the advanced biology group, 32% of the respondents made this error. An approximately equal proportion of students (30%) did not identify leaf fall in autumn as controlled by plant hormones. Sweating in humans was thought to get rid of excess salt (19.8%) or excess water (22.9%), and ca. 59% thought blood distributes heat round the body. As mentioned previously in Chapter Five, 25.7% thought that population growth in the last 1000 years was a linear function, while at least 42% chose an exponential curve, but not the appropriate positively accelerating curve. The respective proportions in the advanced biology group were 17.9% and 45.3%. In a question on an aquatic environment, 18% chose the option that animals produce oxygen and plants produce carbon dioxide. In the advanced biology group, 34.8% thought that during photosynthesis, oxygen is produced from carbon dioxide, rather than from photolysis of water. In both Populations, over 30% thought that organisms can "Adapt themselves to changes in the external environment" rather than being a product of natural selection.

The food web question (item 12, Appendix A) elicited responses that demonstrate some of the misconceptions found by other researchers studying students' conceptions of food webs as summarized in Chapter Three. For example, 35% of the respondents thought that making a change in the highest predator in the web (snakes) would produce no change in the rest of the population. This is consistent with other reports summarized in Chapter Three that state at least 16% of the students held the misconception that altering the density of one population would have no effect on other populations in a food web. In the SISS sample, the next most frequently chosen incorrect response was that removal of a predator at a higher level in a web produces an increase in lower level populations. It is not easy to determine what rationale the students used in reaching this false conclusion, but several possible erroneous conceptions are suggested here for further evaluation. The food web may be viewed by these students as a hierarchical suppressive network. Thus, higher level populations are viewed as suppressing lower level populations. While this is true for the most immediate prey relative to a predator, the rule does not hold for more distant nodes (populations) in the network. Consequently, the misconception that nematodes (i.e. prey for insect larvae) would increase when the snakes that prey on the insects are removed may result from an overgeneralization of this suppression rule. Alternatively, the trophic network may be misconstrued as a "source and sink network" with the highest level population acting as a sink for lower level populations. By removal of the highest level population, the magnitude of the sink would be increased, resulting in greater output of the source(s) further down the network. Additional analytical studies are needed to determine which of several erroneous generalized interpretations of these kinds are used by students who consistently make errors in analyzing trophic network systems.

As presented more fully in Chapter Five, when item response errors are analyzed for schools in the lowest decile as compared to the highest decile, it is not surprising to find that student responses are markedly different. For example on item 10 in Biology Test I requiring interpretation of tabular data, none of the respondents in the highest decile group of schools chose the incorrect distractor labelled A that posited "The larger the animal, the greater the protein concentration in the milk;" while 7% of the students in the schools in the lowest decile chose this response. This response, incidentally, may indicate that the student is unable to use correct correlational reasoning. Over 77% of the students in the schools in the highest decile answered correctly that "The greater the protein concentration in the mammal's milk the faster the newborn baby will double its weight." In the lowest decile schools only 23.6% chose this response. Interestingly, if the student understands correlational reasoning, but compares data only in columns one and two of the table, this may lead to the incorrect conclusion of option A. Some other consistent differences as set forth in Chapter Five, all point to a tendency for certain schools to have a high incidence of misconceptions as reflected in student's responses. The origin of these consistent biases were not determined, based on the data available from the SISS. However, this trend suggests that more in-depth analyses of individual schools is needed to clarify what organizational and instructional factors may account for differences in school outcomes. It is also desirable to determine if the students in the apparently lower achieving schools are indeed as poorly prepared in biology as these items imply or whether some other biasing factor may be mitigating their performance. These preliminary findings however suggest that there may be major differences in the way students in some institutions are perceiving biological information as compared to those who succeed on these kinds of tests. Some of these differences may be explained by using interviews and the "thinking aloud" technique to probe for differences in information processing by those students who succeed compared to those who consistently choose incorrect responses. In the foregoing examples of student "conceptions," it is interesting to note that many of the examples where students made incorrect choices of options involve interdisciplinary topics requiring use of knowledge from mathematics, physical sciences, or systems theory. Since we have no evidence of the comparable difficulty of the items, it is not possible to come to a firm conclusion why responses to these items were among the poorest. But, it suggests that greater attention is needed in developing acumen in integrating information and skills from other disciplines with biological knowledge. In some cases, performance on items with systems diagrams (i.e. network diagrams as in food webs or other ecological interactions) elicited the poorest response. Additional attention to "systems thinking" in secondary school biology curricula may help to ameliorate this apparent deficiency. A wide range of topics can be addressed within a systems perspective. The concept of the cell can be taught as a systems-concept rather than a collection of structural-functional units. In a systems perspective, the component parts are interrelated around principles of interaction that explain how their respective functions contribute to the stability and ordered working of the whole. Similar use of broad systems theory applies to explaining the stable functioning of organismic systems (nervous system, circulatory system, etc.). Ecological concepts are readily embedded in systems-based paradigms[e.g.9-12] and can be used to illustrate broad organizing principles of systems theory beyond reductionistic examples chosen from cellular and molecular biology. The systems theory models need not be highly abstract to serve the organizing functions required for transfer to other topics. Indeed, for many secondary school students, the use of systems theory will need to be introduced as concretely as possible, particularly at the first presentation. However, by consistent use of these principles across biological topics, positive transfer of learning to complex systems such as hierarchical food webs and population dynamics may be improved. Concepts applied from systems theory offer a potentially sound basis for ordering and interrelating topics within general biological education curricula.

Biology Curriculum Organization

The rationale and sequential organization of secondary school biology curricula need to be critically examined in the light of current psychological theory and pertinent content-organizing principles derived from the biological disciplines. One of the objections raised against a national curriculum is that it tacitly suggests that there is only one way of effectively organizing biological knowledge. The BSCS Committee addressed this dilemma by constructing three textbooks emphasizing different themes in biology. The varying levels of difficulty of the texts and differences in content emphasis allowed flexibility in matching the texts to teacher competencies, student interests and student academic preparation.

No information was obtained about the textbooks used by students in the first-year biology or advanced biology samples, therefore it is not possible to determine if there is a relationship between performance and the kind of textbooks, or their mode of use. However, in the preliminary survey data collected in 1985 to 1986, Weiss[13] reports that the most commonly used biology textbooks reported by the schools sampled in grades 7 to 9 were *Focus on Life* (Merrill), *Modern Biology* (Holt, Rinehart and Winston), and *Life Science* (Scott, Foresman). For grades 10 to 12, encompassing the populations studied here, the texts used most often were *Modern Biology* (Holt, Rinehart, Winston), *Biology - Living Systems* (Merrill), *Modern Human Physiology* (Holt) and *Biology Everyday Experience* (Merrill).

When teacher's opinions were obtained about the quality of textbooks used in grades 10 to 12[14], 85% of the sample judged the textbook in their school to be "Clear and well organized." Likewise, 74% responded that the textbook "Explains concepts clearly." However, there is no report of the instructors' opinion of the quality of the sequential organization of the textbook, nor to what extent the instructor chooses a different sequence of readings than the order presented in the text. Given the variation in breadth of concepts presented, and the variations in general organizing perspectives contained in different chapters of a book, the order in which they are read and the way the curriculum is sequenced can be profoundly important to the quality of learning by tenth grade students.

The issue of how to establish a broad understanding of biology at the outset of a learning sequence, while also providing essential fundamental knowledge and skills requisite to specialized topics, has long been a predicament in designing secondary school curricula. Some textbooks begin with a survey of the history, philosophy and methodologies of science followed by cell theory and basic biochemistry. This kind of introduction may provide a good overview of science as a discipline and provides fundamental definitions of life using the cell as unit of structure and function, but to what extent does it give the student an understanding of the broad organizing principles of biology and unifying characteristics of life amidst diversity of species? There is also the perennial question of how well students are motivated by this initial experience. Alternative plans might include an introductory unit on broad principles of physiological ecology preceded by a survey of scientific history and philosophy. A comprehensive overview of human ecology in a comparative physiological ecological context extending downward to include protozoa and prokaryotes (fundamental microbial ecology) could both set an overview of major systems views of biology and permit introduction of cell theory in a context of "unicellular physiological ecology." This approach has been used in organizing a text on Protozoan Biology[15]. A general introduction to the role of humans in an ecosystem and our physiological relationship to the environment (both physical and cultural) may provide a motivational incentive for further interest in biological topics of a more specific kind. A flow-chart outline of an example of this kind of general biology curriculum is presented as Fig. 6.1 (p. 92) in a subsequent section titled "A Systems-Based Model of a General Biology Curriculum." The broad base of principles and patterns established through an overview of physiological ecology at the outset of such a general biology course is followed by additional units addressing cellular, tissue/organ, physiological, and population topics in a systems perspective. Topics in genetics may be introduced at a mid-point in this sequence at a time when sufficient quantitative skills and symbolic learning favor readiness to comprehend the abstract ideas. Furthermore by introducing the topic of genetics at an appropriately early point, additional applications and practice with the quantitative conceptions could be provided in subsequent units on evolution, and advanced ecological concepts. In general, whether the curriculum begins with molecular and cellular topics or more general topics within the biological hierarchy of ideas, it is widely recognized that embedding the content in suitably simplified organizing contexts will enhance knowledge structuring. Moreover, if the problem solving and skill acquisition phases are ordered to include them within broad contexts that may have application at a later point, then transfer of learning is most likely to be enhanced and opportunity for future practice and mastery of the skills is potentiated.

Context-based Acquisition and Transfer of Learning

It is not clear to this author to what extent modern, secondary school biology curricula provide a structured, conceptually-interrelated context to encourage student learning within a knowledge framework that permits recursive application of knowledge and skills toward mastery of scientific content. Most predictive models of mastery learning (e.g. see Chapter Four) assume that recurrent practice, appropriately distributed and included within the most relevant context for further application, is required for full mastery of content. In many cases, textbooks appear to contain a well-ordered but sequentially disjunctive set of chapters. These provide little opportunity for students to build scientific thinking skills or to re-apply prior gained information and skills to new content. As a consequence there is little opportunity to acquire biological competency in a systematic and increasingly refined context. If this contextual framework is lacking in many textbooks, it is equally unclear if teachers have implemented such an overarching framework to provide the kind of structured learning that may enhance mastery of biological content. Recent publications decry the plethora of terms that biology students are usually required to learn (as also cited in Chapter Four) These studies, using a limited number of sample words, often show little gain in word knowledge across grade levels. In some cases, recommendations are made to reduce the number of scientific terms to be learned. However, it is also widely recognized that the biological sciences, more than other sciences, are based on diverse categorical kinds of knowledge that often require more vocabulary acquisition. While it is reasonable to decry an over-reliance on learning rote terminology, it is not reasonable to assume that young people, who are in one of the most productive phases of their intellectual development, cannot be exposed to a wide diversity of words and ideas. The question may be expressed more productively as "what context for, and recursive use of, word units best enhances meaningful acquisition of biological ideas. A corollary to this is, "What learning environments provide an efficient means of acquiring biological words and their meanings in a way that permits widest application to, and subsequent cognition in, similar or divergent contexts?" This also suggests that a greater effort is needed to systematically identify vocabulary that is most productive for future scientific growth and an ability to comprehend scientific communications. Given the frequently cited problem of excessive terminology in biological education, we may need to examine how to use scientific word etymology more effectively. To increase the efficiency of teaching word comprehension in biology, the major classes of terms used in biology can be identified and the major semantic elements used to classify them into contextual categories can be set forth. This could especially aid the student who is destined to be a citizen consumer of scientific information and at least needs to be able to conceptually categorize the general field of science that is referenced by the communication, if not to make a more complete interpretation of its meaning. We need additional research to clarify the most appropriate strategies for developing these conceptual categorizing skills, and the best sequence of experiences to ensure an orderly and psychologically sound set of maturational experiences.

This problem includes development of quantitative reasoning. It appears that biology curricula give little systematic attention to developing a continuous program of maturation in quantitative skills. Basic mathematical tools are introduced sporadically, usually when they are applied to problems in genetics, physiology, or sometimes in interpreting ecological processes. Unfortunately, this sporadic introduction sometimes also comes in conjunction with science learning that is highly abstract. This is particularly true for learning genetics. A more reasonable approach might include early attention to applying fundamental quantitative skills in varying contexts as the biology curriculum progresses. Proportional reasoning can be used at varying stages of the curriculum, especially commencing early in the program, to better prepare students for application of proportional reasoning to genetics when it is introduced. This also pertains to the construction and interpretation of graphs. In Chapter Five, the correlational data suggest that basic mathematical competencies as assessed by the SISS. mathematics test account for a significant amount of variance in the performance on the Biology Test items. These data, while not perfectly controlled for other contributory variables, suggest that enhanced understanding of basic mathematical principles can transfer to biological problems of the kinds presented in the SISS test items.

A systematic and carefully planned program of introducing quantitative reasoning skills in the context of learning that is most likely to be useful at a later point is well considered. For example, while studying cell mitosis and meiosis, early attention to proportional reasoning may provide transfer value to latter applications in genetics when proportional reasoning is applied to predict genotypes of offspring. By providing practice in determining proportions of chromosomes distributed to daughter cells during meiosis, the students may become more adept at using these quantitative skills when the meiotic events are applied to genetics problems at a later point in the curriculum. The general practice of teaching biology as a non-quantitative discipline may also be broadly deleterious to the student's advancement in science education at the secondary level. Given our current sequential arrangement of courses, progressing from biology to chemistry and often culminating with physics in the twelfth grade, insufficient attention to quantitative reasoning skills in the tenth grade and earlier in pre-secondary school science courses may limit the student's ability to transfer knowledge gained in mathematics courses to more quantitatively based disciplines such as chemistry and physics. Applying quantitative skills to biological phenomena may not only reinforce mathematics learning, but provide a more logically interconnected and stable understanding of the biological information. It is clear, however, that the applications need to be carefully planned to match the intellectual level of development of the learner and to best complement the biological phenomena being presented. Forethought is also required to introduce those mathematical skills in the context most appropriate for later use in the biology curriculum to ensure that the quantitative ideas are reinforced and used sufficiently often to produce reasonable levels of mastery. This is also true of basic scientific reasoning skills that are often introduced once or several times sporadically and never applied again.

Particular attention is needed toward refining our strategies in teaching genetics at the secondary school level. Current research as cited in Chapter Three indicates that the problem is compounded by the interaction of several variables including: 1. limitations of formal reasoning ability of the students, 2. the abstractness of the concepts, 3. high cognitive demand occasioned by the use of symbols in representing generations and genotypes, etc., 4. the conjoint demands placed on the students of applying quantitative skills at the same time they are required to comprehend complex gene interactions, and 4. the prevailing practice of teaching genetics in isolation from other biological content thus reducing the opportunity for students to gain mastery of the content by practicing problems and applying genetics concepts in appropriate diverse contexts. While there is limited evidence to suggest that we can improve particular aspects of formal reasoning level of students by sustained and intensive intervention, it is unlikely that major changes can be induced in the course of time available to the biology instructor before genetics is taught. Perhaps, a more intensive effort beginning in the elementary school and extending into the junior high school might improve the situation. Current evidence, however, suggests that the problem is complex and that it is more productive to adapt instruction to match the cognitive development of the student than to expect remarkable changes within a short period of time. Therefore, more careful planning and preliminary preparation through presentation of enabling concepts and skills in advance of genetics instruction may improve the students capacity to comprehend the material. As mentioned above, some careful attention to applying symbolic notations and quantitative skills while teaching cell meiotic processes, coupled with clear discussion of the relevance of these phenomena to reproduction and gene segregation, can serve as an advance organizing perspective to aid student comprehension of genetics concepts involving gene segregation and recombination. Furthermore, greater care in using consistent concrete representations of meiotic events along with symbolic representations may enhance later transfer to genetics by using the concrete referents to bridge into the more abstract relations represented by genetics. For example using figural representations of cells and chromosomes along with the symbolic representations in a consistent way can serve as a place keeping device for the students as they gradually master the symbolic expressions assigned to alleles in genetics. Furthermore, planning instruction to carefully order problems from more simple to complex and providing sufficient in-depth practice of a given problem type using diverse examples of living organisms, may enhance mastery of genetic concepts. It is probably wise to embed each problem set in a sufficiently broad context of examples to enhance generalizability of the learning. There is a wide literature base presenting examples of genetic crosses for diverse organisms spanning protozoa to humans[16-18]. Moreover, current information processing paradigms suggest that for teaching genetics, as with other high level learning, active student involvement is important in acquiring and applying genetics problem-solving skills. Examples of interactive techniques to encourage student discussion and application of genetics problem solving skills have been published previously. These include the use of "Breeder's Problems" to stimulate students to use practical examples of animal and plant breeding problems while learning basic genetics concepts[19]. Computer programs are also available, some of them well designed, to encourage creative applications of genetics problems using examples of organisms that are familiar to most secondary school biology students[20].

While exposure to a broad range of experiences is undoubtedly enriching during the cognitively important formative years of adolescence, some attention to developing a sense of precision in one's work, and an appreciation for quality in one's product, is also of importance to further academic work in science education and in preparation for responsibilities as a citizen. Toward this end, much greater attention is recommended toward encouraging students to apply skills in varying contexts to increase skill mastery, rather than dispersing learning over a broad range of experimental techniques and diverse scientific reasoning skills. Moreover, a clear conceptual preparation for laboratory experiences should precede most complex enquiry laboratory learning experiences. It is neither scientifically sound nor cognitively reasonable to expect that many of our secondary school biology students can enter into an open-ended laboratory experience and master both scientific skills and re-invent basic scientific knowledge. A clear construction of intended goals, plans for procedures, and relevant background knowledge for experimental tasks should precede laboratory learning. To do otherwise is to inculcate an erroneous attitude that scientists enter the laboratory intellectually unprepared and begin experiments without preliminary attention to theory or conceptual rationale. Laboratory experiences should be carefully designed to progress toward increasingly formal and more complex skill usage. And each laboratory in so far as possible should be fully integrated within a theme of the curriculum that has been sufficiently explored conceptually to provide a sound knowledge structure for the laboratory experience.

A Systems-based Model of a General Biology Curriculum

The flow-chart in Fig. 6.1 (p. 92) contains a sequence of topics for a biology curriculum that exemplifies one plan of using broad organizing principles at the beginning of the curriculum experience to set a framework for subsequent learning and provide the basic experiences with scientific and quantitative skills to be used recurrently in subsequent units toward mastery of the content. The flow-chart is divided into thematic units (rows) containing subunits (boxes) connected by horizontal arrows and assembled in a stratified sequence (vertical arrows) showing the temporal order of the experiences. Each subunit also is labelled with the approximate percent of total curriculum time that could be allocated to it. This is only a guide and certainly is not an invariant prescription for time allocation.

The first thematic unit is an introductory unit on scientific inquiry principles focused on a comparative analysis of some research strategies and their rationales used in ecology, experimental physiology, and cellular and molecular biology. This Unit provides a historical and philosophical rationale for scientific research compared to other ways of explaining experience. More importantly, it should introduce fundamental ways that biologists think about the field as represented by different subdisciplines. Thus, analyses of ecological research paradigms should include the use of quadrats and proportional reasoning as applied to proportions of species occupying a quadrat. Graphical representations of gradients temporally and spatially can be introduced as one of the tools (though not exclusively) employed by ecologists to represent variations in species geographically and temporally. Diversity of species occupying a region can be represented by diversity indexes. Population growth curves can be introduced at this time. In general, a <u>first understanding</u> of systems theory should be presented showing network diagrams (e.g. foodwebs, exchange of gases such as oxygen and carbon dioxide, etc.). Examples of controlled experiments in ecology can be compared to those in experimental physiology. The role of basic systems theory in understanding the physiological functions of living organisms may also be introduced at this time to reinforce the conceptions introduced earlier in the unit in the context of ecology. Modern tools of cellular biology including electron microscopy should be considered here. Quantitative measures applied to structures in electron micrographs, compared to those in light micrographs, can clarify the enhanced resolving power of electron optical instruments. Moreover, skill in proportional reasoning can be practiced by computing magnifications and comparing sizes of objects as viewed in light micrographs with those in higher magnification electron micrographs, etc.

The second thematic unit (row 2) introduces the student to highly general organizing principles about the nature of living systems, beginning with an exploration of human physiological ecology (Subunit 2A). The objective of this subunit is to set forth some characteristics of life (nutrition, metabolism, irritability, growth, and reproduction) in the context of how humans have adapted to their environments. This unit permits exploration of nutrition, growth (individual and populations), basic modes of adaptation to varying environments, role of fundamental metabolism and homeostasis, and reproduction in a context of physiological ecology. Emphasis should be placed on patterns and general organizing principles with sufficient concrete exemplars to make the generalizations understandable by students who are not fully formal operational. The second subunit (2B) considers these themes in the context of animal populations, then plants (2C), and finally protozoa and microbes (2D). The latter subunit is used as a transition into a unit on cellular biology. The functions of a cell are introduced here for the first time as examples of adaptations by unicellular organisms, thus establishing a meaningful context for a discussion of the varied cell organelles and their functions. Subsequently in Unit 3, these cell concepts are generalized to include those in all organisms (distinguishing between prokaryotes and eukaryotes). The essential organizing principle of the transition from Unit 2 into Unit 3 is to use the prior general ecological data on the nature of life to explain how unicellular organisms have adapted to their environment. This is a structural-functional theme organized around autecological topics at the cellular level.. That is, the physiological ecology of individual moneran and protozoan species is presented as an exemplar of more general ways organisms adapt to their environment. Since Protista are single-celled organisms (yet some are quite large as for example *Blepharisma* sp., *Spirostomum* sp., or *Physarum*, known as the slime mold), the role of their cellular components in maintaining stable life processes can be made vividly and concretely clear to secondary school students. Moreover, some are sufficiently easily maintained and observed in the laboratory to allow inquiry laboratory experiences with the organisms to expand student knowledge and skills in cellular physiological ecology. This emphasis on the role of cell organelles in maintaining the life of a unicellular organism helps to eliminate the abstract and rote quality of learning that sometimes accompanies cell topics when introduced as the unit of structure and function of life quite apart from the adaptive features of relevant organisms.

The third unit fully explores the functioning of cells, once again in a context of structural functional relations, but in a more general perspective. The concept is enlarged to include the cell as the basic unit of structure and function for all living things, including higher forms of life. The cell cycle is presented with a clear emphasis on mitosis and meiosis in a context that will transfer to genetics (as described in Chapter Six). Throughout these first two units, quantitative skills are used to interpret graphs, especially population growth curves (applied repeatedly throughout subunits 2A to 2D), proportions are used to express, among other concepts, the proportion of nutrients consumed in various foods, demographic and population data for organisms in various geographic locales, and use of mathematical formulas for diversity measures. In the transition into the topic of cell science, symbolism is introduced to mark chromosomes, identify biochemically significant compounds, and thus prepare the students for the more abstract learning in genetics. If the class is more able, genetics can be introduced immediately following the cell unit (Unit 3), but if they are less- able, it is probably best introduced more midway into the course of study after the physiology unit (Unit 4) as shown in the flow chart.

Unit 4 is a structural functional analysis of organs and systems in a context of further explaining the broad physiological ecological adaptations presented in Unit 2. Here, however, progression in subunits is from the "simpler organisms" to the more complex culminating in a major examination of human biology. This progression links naturally into the last topics of Unit 2 and also Unit 3, and provides a quasi-phylogenetic sequential survey across taxa that will serve as a contextual organizer for the evolutionary topics immediately following the genetics unit. In Unit 4, the emphasis is on expanded systems theory. Organisms are examined for structural functional correlates to explain how they sustain a balanced set of processes exemplified by the basic life characteristics introduced in Unit 2. Thus, plant organs and their physiology are examined for structural-functional relations and coordination of action to explain how they have adapted as primary producers in terrestrial and aquatic environments. This is followed by an examination of invertebrates of increasing complexity, with an emphasis on systems analysis of their physiological functions. At each level of increasing organismic complexity, the qualities that make them more efficient, and hence better adapted, are set forth. Finally, human physiology (subunit 4C) is examined in the context of adaptations that maintain life processes at a finer level than introduced in subunit 2A. A more complete analysis of physiological systems is made including the corresponding systems that mediate life functions, e.g. digestive system (nutrition), circulatory system (nutrition and homeostasis), endocrine system (homeostasis and control of growth, etc.), nervous system (irritability and coordination), and skeleto-muscular system (support and locomotion), reproductive system, etc.

Genetics is introduced in Unit 5, if it has not been introduced immediately after Unit 3. This should include molecular genetics. Classical genetics topics, moreover, can be used as an explanatory principle for the continuity of life, and as an explanatory mechanism for the varied structural-functional adaptations introduced in the foregoing units. It also sets a perspective for evolutionary biology by providing a mechanism to be used in explaining among other concepts natural selection, and survival of the best adapted. The basic quantitative skills developed here are used recursively throughout the evolutionary discussion and subsequent population biology subunit to explain parent-offspring relations and the effect of natural selection on population composition. It is critically important in this curriculum perspective to apply the genetics principles recursively throughout subsequent sections in appropriately simplified problem contexts to permit practice and mastery of analyzing genotype and phenotype proportions produced by genetic crosses.

The evolutionary survey commencing in Unit 5 (subunit 5A) provides a broad introduction to the kingdoms of living organisms and also allows taxonomy to be introduced in a meaningful context of phylogenetically based categories of living things. This is followed by discussions of populations, and ecology (amplifying the information provided in Unit 1) including community, ecosystem, and biome analyses. These topics progress through a discussion of community structure (subunit 6B) and larger ecosystems concepts (subunit 6C). Considerable care should be given to applying fundamental quantitative skills acquired in Units 2 to 4 and expanding the students' understanding of the kinds of contexts where the quantitative measures are appropriate. Additional practice in analyzing food webs and ecosystem network diagrams, and using graphical and numerical skills, should be provided.

A final unit on environmental science (Unit 7) may be presented. Where appropriate, quantitative skills acquired in Units 1 , 2, and 6 are re-applied here including graphical analyses of population growth, network models of communities (including foodweb analyses) and the varied mechanisms whereby populations maintain a reasonable degree of stability in the face of varying environmental pressures. The dynamics of predator-prey interactions, growth and death rates in populations, and the synergistic or inhibitory relations among species in communities should also be explored using appropriately simplified mathematical models or representations. The role of humans in maintaining these delicate balances, both as an aesthetic and practical measure, should be explored as a constant theme throughout this final unit.

Figure 6.1 A Flow-Chart of a Systems-Based General Biology Curriculum

Units | Themes

1. Introduction to scientific inquiry in a context of comparative analyses of ecological, physiological, and cellular-molecular research methodologies. (2.5%)

2. A. Human Biology in a broad ecological view based on physiological adaptations. (5%) → B. Animal Biology in a broad ecological view based on adaptations as in A. (5%) → C. Plant Biology in a broad ecological view based on adaptations as in A & B. (5%) → D. Protistan & Microbial ecology with a transition into cellular function of these unicells. (5%)

The organizing principle for this unit is the idea of organismic adaptation to varied environments beginning with humans as the most immediately relevant and closest experiential base for the students. Basic quantitative skills of interpreting graphs of population growth, species diversity, and proportions of individuals in a geographical locale, including nutrient composition analysis by proportions, are used throughout A to D. In each subunit, the information is ordered within a theme of the basic defining attributes of life, Obtaining energy, Metabolism, Growth, Reproduction, etc. The structure-functional analysis of unicells leads into unit 3.

3. The cell is presented first in a context of physiology of prokaryotes and eukaryotes using structure-functional analyses within a systems perspective of organelle interactions, including biochemistry. Then it is generalized to higher organisms. (10%)

4. A. Plant Anatomy & Physiol. in a systems perspective. (5%) → B. Invert. & vert. Anat. & Physiol. in a systems perspective. (10%) → C. Human Anat. & Physiol. in a systems view. (15 - 20%)

The sequence is intended to link into the discussion of protistan cellular dynamics and progress from phylogenetically lower to higher organisms. This sequence and its concurrent context of a systems perspective of organ interactions (increasingly efficient adaptations to environmental pressures) is used as an organizing structure for the following topics in genetics and evolutionary biology.

(Continued)

Figure 6.1 (Continued)

5. The basic principles of genetics are introduced as an explanation for the diversity of form and function presented in preceding units. The quantitative skills used in Units 2 through 4 are further expanded here by symbolic, graphical and quan. analyses of Mendelian genetics. The concepts are introduced as a rationale for explaining evolutionary history as presented in the next unit. Molecular genetics is introduced here, and its historical origins in prokaryote research is set forth.

(15 - 20%)

6.

A. Evolutionary & Population Biology. The concept of species is presented as a unit of population and as a product of evolution with genetics used to explain natural selec.

(5%)

B. Community Biol. A systems view of the interaction of populations in a syn-ecological perspective. An expansion of Unit 2 to include additional use of evolutionary & genetic concepts.

(5%)

C. Ecosystems and Biome Analyses. The major habitats and the organisms adapted to them are discussed as a higher order systems concept.

(5%)

This unit is designed to expand the generalized perspectives in Unit 2 to include a more refined analysis of populations , the evolution of species, and their interactions in a systems view of synecology. Quantitative skills of graphing population growth, species interaction (e.g. predator-prey interactions), diversity indexes, and mapping ecological concepts as graphical expressions are used. This is intended to expand the systems thinking skills of the students, aid mastery of quantitative reasoning skills, and bring the foregoing knowledge structures into a more coherent and clearly linked framework of concepts.

7. This unit may include a survey of environmental science as a way of bringing the curriculum to a full circle, closing back upon the general ideas of human ecology introduced in subunit 2A. Our relation to the environment in a systems perspective and our responsible use of the environment may be included here.

(25%)

Note: The percentage time given for each subunit is a general approximation. Adjustments in time allocations should be made in relation to student preparation, community interests and ideals, and the interests and best insights of the instructor.

Comment

On the whole, it is clear that with respect to some of the most pressing questions of how to organize instruction for maximum transfer to new learning situations, or particularly to future applications beyond the classroom, our knowledge is limited. Moreover, the wide range in student test scores and the large variance across schools reported from the SISS research, highlights the heterogeneity of U.S. school populations. This suggests that additional attention to curriculum reform in the light of student individual differences may be necessary. Current research, using information processing paradigms, methods of exploring the relationship between student construction of knowledge and classroom teaching strategies, the role of communication and cognitive structure in mediating knowledge and skill acquisition, promises to yield new insights for future applications. This summary has presented many more questions for further research and for curriculum product development than it has provided answers. I trust, however, that it may stimulate thought about creative and diverse ways of organizing secondary school instruction to make biology learning both more enjoyable and academically sound. In this most important task, the secondary school biology instructor as scientist and instructional expert can serve a significant role. Moreover, by combining their scholarly, practical knowledge with results from investigations at research centers, we should be able to make significant gains in the quality and quantity of science acquired by our secondary school students. No task is of more fundamental importance to our society, nor of more lasting consequence to the development of an internationally informed and literate global community.

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APPENDIX A:

BIOLOGY CONTENT TEST I

THIRTY BIOLOGY TEST ITEMS PRESENTED TO FIRST-YEAR BIOLOGY STUDENTS

NOTE: Item analysis data are presented in a chart following each item as explained in the following sample diagram.

Year of testing when the same item was used for comparison among groups.

Age group tested: B1 = 1st year biology, B2 = 2nd year biology, 1 = 10-yr. olds or that grade wherein they were enrolled, and 2 = 14-yr olds or equivalent grade (see P.49)

Test item number and % of respondents who answered correctly in U.S. and Intl. samples (see pp. 61-62).

(OTL = Teacher rating of students' opportunity to learn test item content.)

			% Correct					
Year	Pop	Item #	All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis. (Rel. measure)
1986	B1	(B107)	66.2	65.0	66.9	NA	20.0	.19
1983	2	(2M03)	62.7	59.5	65.5	NA		.19
1970	1	(1B/7)	47.2	45.4	49.3	45.1		.24

1 If equal amounts of the following foods are eaten, which one would provide the most protein for the body?

A potatoes

B apples

C rice

D bread

E chicken

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B101)	43.4	45.5	41.5	NA		.27
1983	2	(2D07)	47.2	47.7	47.9		21.0	.37

2 What is the main way that sweating helps your body?

A It cools your body.

B It keeps your skin moist.

C It keeps you from catching cold.

D It gets rid of the salt in your body.

E It gets rid of excess water in your body.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B102)	54.4	51.1	58.6	NA		.40
1983	2	(2D08)	47.5	41.5	54.0		34.0	.47

3 What adaptation characteristics would one probably find in desert plants?

A large leaf area and a thick impermeable leaf surface

B large leaf area and a large absorbing root surface

C small leaf area and a large absorbing root surface

D small leaf area and a thick, permeable leaf surface

E small leaf area and a small absorbing root surface

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B103)	46.5	42.5	51.3	NA		.21

4 A girl found the skull of an animal. She did not know what the animal was but she was sure that it preyed on other animals for its food.

What clue led to this conclusion?

A The eye sockets faced sideways.

B The skull was much longer than it was wide.

C There was a projecting ridge along the top of the skull.

D Four of the teeth were long and pointed.

E The jaws could move sideways as well as up and down.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B104)	70.5	66.4	74.3	NA		.34
1986	2	(2M09)	66.1	59.5	72.3	NA		.37
1983	2	(2M09)	74.9	69.9	80.5		23.0	.36
1970	2	(4B/3)	67.7	62.9	73.4	63.3		
1986	1	(1M08)	52.9	47.7	57.1	NA		.35
1983	1	(1M08)	57.1	54.2	59.7		30.0	.37
1970	1	(1B/6)	42.5	40.1	45.3	46.4		.36

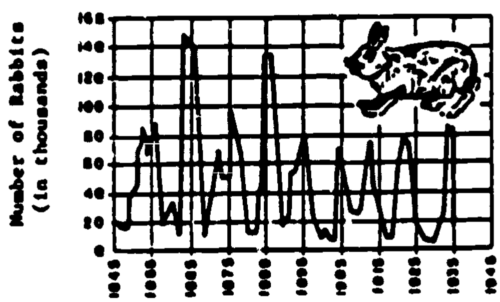
5 Which of the cells shown below would commonly be found in the human nervous system?

A B C D E

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B105)	39.4	36.7	42.9	NA		.29
1983/84	3P	(3M08)	53.8	46.7	58.2		7.0	.30
1983/84	3N	(3M08)	31.0	26.5	36.6		NA	.31
1986	2	(2M11)	28.2	20.8	35.2	NA		.23
1983	2	(2M11)	28.3	21.7	35.5		25.0	.24

RABBIT POPULATION

6



According to the graph, which of the following would most likely have been true in 1865?

A There was plenty of grass and few foxes.

B There was little grass and few foxes.

C There was plenty of grass and many foxes.

D There was little grass and many foxes.

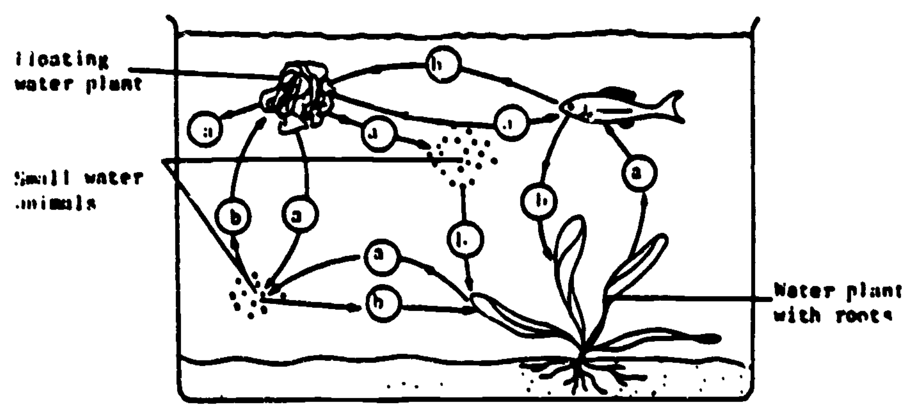
E One cannot tell from the information given.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B106)	48.6	44.5	53.7	NA		.30
1983	2	(2C14)	46.4	43.9	49.4		31.0	.27

7 A boy sitting under a tree watched a bird getting insects from between the cracks of the bark. Which drawing shows the kind of beak this bird would have had?

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B107)	66.2	65.0	66.9	NA		.19
1986	2	(2N03)	62.7	59.5	65.5	NA		.19
1983	2	(2N03)	69.1	65.3	73.1		20.0	.23
1970	2	(4A/4)	60.7	57.9	63.9	60.4		
1986	1	(1N07)	47.7	46.9	49.3	NA		.19
1983	1	(1N07)	53.2	48.4	57.7		30.0	.20
1970	1	(1B/7)	47.2	45.4	49.3	45.1		.24

8 The diagram below shows an example of interdependence among aquatic organisms. During the day the organisms either use up or give off (a) or (b) as shown by the arrows.



Choose the right answer for (a) and (b) from the alternatives given.

A (a) is oxygen and (b) is carbon dioxide.

B (a) is oxygen and (b) is carbohydrate.

C (a) is nitrogen and (b) is carbon dioxide.

D (a) is carbon dioxide and (b) is oxygen.

E (a) is carbon dioxide and (b) is carbohydrate.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B108)	67.3	67.9	67.2	NA		.34
1983/84	3P	(3M07)	86.4	82.9	88.6		8.0	.35
1983/84	3N	(3M07)	73.3	72.5	74.3		NA	.34
[illegible]	3P	(11B/2)	81.2	70.2	84.7			
1970	3N	(11B/2)	68.4	65.6	72.3			
1986	2	(2N03)	62.4	60.8	63.8	NA		.34
1983	2	(2N08)	70.4	69.3	71.7		30.0	.39
1970	2	(4B/7)	64.1	63.2	65.2	48.7		

9 Some seeds germinate (start to grow) best in the dark, others in the light, while others germinate equally well in the dark or the light. A girl wanted to find out by means of an experiment to which group a certain kind of seed belonged. She should put some of the seeds on damp newspaper and

A keep them in a warm place in the dark.

B keep one batch in the light and another in the dark.

C keep them in a warm place in the light.

D put some on dry newspaper and keep them in the light.

E put some on dry newspaper and keep them in the dark.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B109)	83.0	85.6	79.3	NA		.27
1983	2	(2A01)	82.0	84.7	79.0		37.0	.34
1986	1	(1M13)	50.0	51.2	49.6	NA		.35
1983	1	(1M13)	55.2	56.8	53.4		37.0	.38
1970	1	(1B/10)	53.5	53.8	51.5	40.3		.45

10 The following results are from experiments which were made to find how long it took for newborn babies of different mammals to double in weight.

Mammal	Time in days to double the weight of the newborn baby	Percentage protein in the milk of the mother
human	180	1.6
horse	60	2.0
cow	47	3.5
pig	18	5.9
sheep	10	6.5
dog	8	7.1
rabbit	6	10.4

What do the results of these experiments suggest?

A The larger the mammal, the greater the protein concentration in the milk.

B The smaller the mammal, the greater the protein concentration in the milk.

C The greater the protein concentration in the mammal's milk the slower the newborn baby will double its weight.

D The greater the protein concentration in the mammal's milk the faster the newborn baby will double its weight.

E There appears to be no relationship between protein concentration in mammal's milk and time taken for a newborn baby to double its birth weight.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B222)	69.1	65.9	72.8	NA		.39
1986	B1	(B110)	49.5	49.5	49.3	NA		.38
1983/84	3P	(3M22)	78.7	76.6	79.7		11.0	.41
1983/84	3N	(3M22)	54.4	54.0	54.8		NA	.46
1983	2	(2A08)	50.7	50.1	51.2		30.0	.45

11 All of the following are aspects of the reproductive process. Which one of them must occur before we can be certain that fertilization has taken place?

A A male organism must find a mate.

B Reproductive organs must be produced.

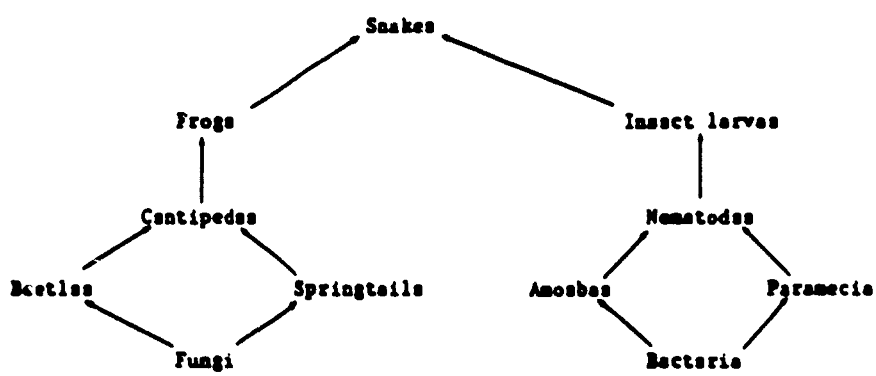
C The nucleus of a male gamete must fuse with that of a female gamete.

D A spermatozoon must reach an egg cell.

E A female gamete must provide a store of food for the embryo.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B224)	58.2	53.7	62.8	NA		.34
1986	B1	(B111)	40.3	37.6	43.6	NA		.34
1983/84	3P	(3M09)	58.9	55.5	61.2		5.0	.39
1983/84	3N	(3M09)	38.9	38.4	39.4		NA	.37
1970	3P	(10A/7)	52.9	55.4	52.1			
1970	3N	(10A/7)	34.6	33.8	35.9			

12 The following diagram illustrates a food web.



If all the snakes are removed, which one of the following changes would probably occur in the next two years?

A The number of nematodes would increase.

B The number of frogs would decrease.

C The number of insect larvae would decrease.

D The number of centipedes would decrease.

E There would be no changes.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B112)	28.8	22.4	37.6	NA		.40
1983/84	3P	(3M15)	57.4	47.8	63.2		4.0	.42
1983/84	3N	(3M15)	27.1	22.8	32.4		NA	.47

13 Which of these substances is found in every living cell?

A protein

B chlorophyll

C cellulose

D starch

E hemoglobin

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B210)	59.7	55.4	65.8	NA		.28
1986	B1	(B113)	48.6	45.7	51.4	NA		.17

14 Which one of the following processes in plants is not controlled by hormones?

A water uplift in the stem

B downward growth of the radicle

C flowering under the influence of increasing day length

D falling of the leaves of deciduous trees in autumn

E orientation of shoots towards lateral light

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B217)	37.2	33.4	41.6	NA		.41
1986	B1	(B114)	29.3	27.2	31.7	NA		.25

15 Why is it that your body temperature does not fall even though you lose heat continually?

A The blood distributes heat round the body.

B Respiration results in the liberation of heat.

C Heat is constantly being absorbed from the Sun.

D Hot meals are eaten regularly.

E Warm clothes are good insulators.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B115)	27.3	27.9	26.7	NA		.06
1983/84	3P	(3M13)	30.6	29.2	31.5		6.0	.10
1983/84	3N	(3M13)	22.0	21.9	22.1		NA	.08
1970	3P	(11B/5)	33.9	37.9	32.6			
1970	3N	(11B/5)	28.7	28.8	28.6			
1970	2	(4A/10)	21.7	22.6	20.4			.05

16 How does natural selection operate in a population?

A The members are all alike.

B The members are equally able to survive any environmental change.

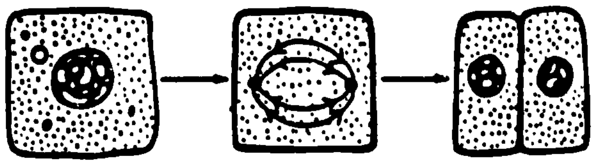
C The members differ so only some survive when the environment changes.

D The members do not adapt to environmental changes.

E The members of the entire population adapt to environmental changes.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B227)	60.4	60.2	61.7	NA		.44
1986	B1	(B116)	51.7	54.7	49.4	NA		.36

17 The following diagrams represent a cell process.



If the cell in Diagram 1 contains four chromosomes, how many choromosomes would be present in each cell in Diagram 3?

A 1

B 2

C 4

D 8

E 16

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B201)	42.1	36.0	49.9	NA		.40
1986	B1	(B117)	29.2	26.5	32.8	NA		.34

18 What initially determines whether a human baby is going to be a male or a female?

A The DNA in the sperm.

B The DNA in the egg.

C The RNA in the sperm.

D The RNA in the egg.

E The DNA and RNA in both sperm and egg.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B202)	48.5	47.6	49.1	NA		.33
1986	B1	(B118)	31.8	31.2	32.4	NA		.33

19 The Galapagos Islands in the Pacific are believed never to have been connected to the mainland. In the Islands there are about 14 species of finch-like birds with few obvious relatives except on the South American mainland. The finches vary from island to island. There is a close resemblance between species in plumage, calls, nests, and eggs, but each species differs greatly in beak structure according to the diet. The species do not interbreed and do not compete for food.

It is stated on this evidence that isolation from the South American mainland and different habitats on the Islands are important factors in the production of new species.

A The statement is supported by the information given.

B The statement is not supported by the information given.

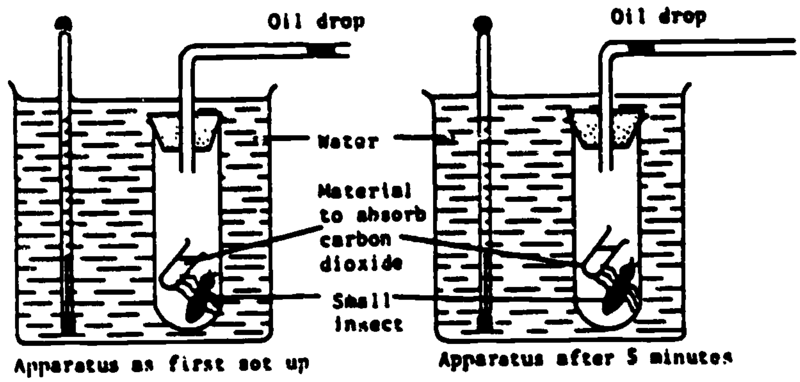
C The statement is contradicted by the information given.

D The statement is known to be false but this is not supported by the information given.

E No relevant information is given.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B229)	45.9	43.1	50.7	NA		.21
1986	B1	(B119)	44.9	44.6	45.5	NA		.30

20 Animals take in oxygen and give out carbon dioxide. Ordinary air contains very little carbon dioxide.



Which of the following can be measured with the above apparatus?

A The rate of movement of the animal.

B The amount of heat produced by the animal.

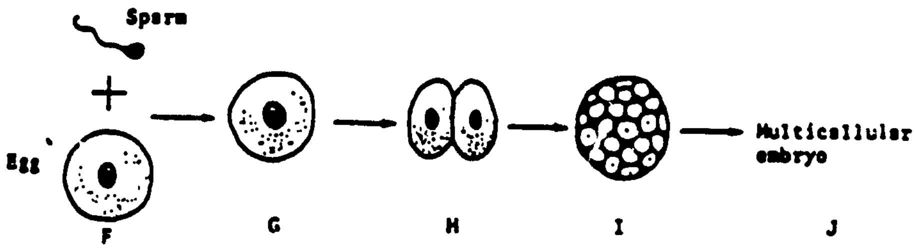
C The rate of respiration of the animal.

D The effect of carbon dioxide on the animal.

E The amount of carbon dioxide absorbed by the animal.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B225)	45.2	39.5	53.2	NA		.33
1986	B1	(B120)	32.8	27.0	40.1	NA		.28
1983/84	3P	(3M10)	57.5	49.2	62.7		5.0	.37
1983/84	3N	(3M10)	37.1	31.8	44.2		NA	.39
1970	3P	(10A/27)	52.4	42.8	55.5			
1970	3N	(10/A27)	33.7	27.0	43.2			
1986	2	(2M12)	31.2	26.3	35.7	NA		.15
1983	2	(2M12)	35.3	29.4	41.6	NA	21.0	.27
1970	2	(4B/31)	35.1	30.5	40.5	37.2		.31

21



Where would the process which occurs between F and G normally take place in humans?

A uterus

B ovary

C testis

D oviduct

E vagina

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B203)	32.1	2[illegible].0	36.8	NA		.32
1986	B1	(B121)	20.7	19.0	22.4	NA		.23

22 The diagrams represent three cells with membranes of different permeability. The dots show sugar molecules which cannot pass through the cell membrane.

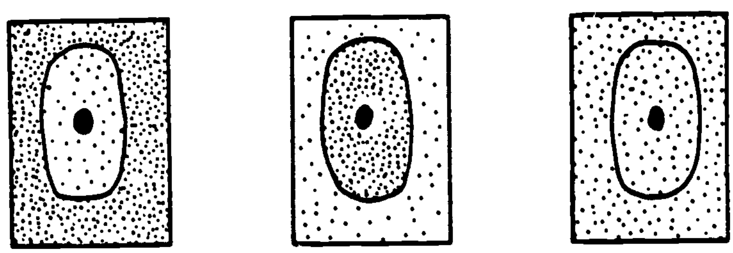


Diagram 1 Diagram 2 Diagram 3

Into which cell(s) will the most water molecules diffuse in from the outside?

A 1 only

B 2 only

C 1 and 2 only

D 2 and 3 only

E 1, 2, and 3

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B204)	44.2	43.4	44.9	NA		.22
1986	B1	(B122)	37.0	37.3	37.3	NA		.10

23 Two alternative color characteristics in mice are "hooded" and "white." When homozygous parents of both colors are crossed all the offspring are hooded. If these F_1 hooded rats are mated together and produce litters totalling 50 rats, which of the following proportions is most likely?

A 50 hooded : none white

B 50 white : none hooded

C 38 white : 12 hooded

D 24 white : 26 hooded

E 10 white : 40 hooded

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B207)	31.2	30.5	30.7	NA		.30
1986	B1	(B123)	22.4	22.5	22.3	NA		.25

24 In a population of 1000 fruit flies, the percentages of gene pairs were:

TT = 15 percent Tt = 51 percent tt = 34 percent.

If the fruit flies were free to breed normally, and if nothing happened to distrub the "gene pool", what would be the approximate percentage of tt two generations later?

A 15 percent

B 34 percent

C 51 percent

D 68 percent

E 75 percent

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B208)	38.7	39.0	37.2	NA		.35
1986	B1	(B124)	34.7	35.2	34.4	NA		.18

25 In many breeds of cattle the polled condition (absence of horns) is dominant over the presence of horns, and homozygous red crossed with homozygous white produces roan (intermingled red and white hairs) color. Which of the following crosses will produce only horned roan offspring?

A polled red x horned white

B horned roan x horned roan

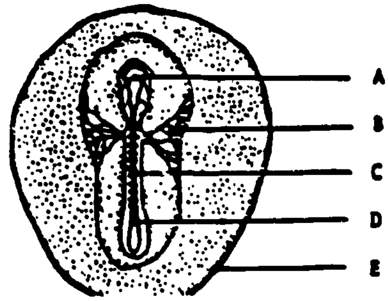
C horned red x horned white

D polled roan x horned roan

E polled white x horned roan

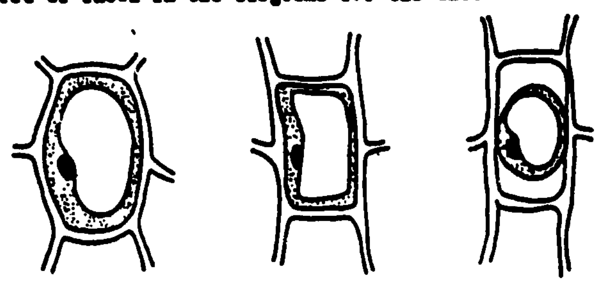
Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B209)	43.2	41.6	45.7	NA		.29
1986	B1	(B125)	37.1	37.3	37.8	NA		.18

26 The diagram shows a 33-hour chick embryo. Which structure brings food to the growing embryo?



Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B221)	57.7	55.4	61.5	NA		.31
1986	B1	(B126)	46.9	45.7	48.3	NA		.25

27 Similar fragments of a certain plant tissue were placed in 1%, 9% and 15% sugar solutions respectively. When viewed under the microscope after they had reached equilibrium with the bathing solution, single cells appeared as shown in the diagrams for the three solutions.



1 per cent solution — Diagram 1
9 per cent solution — Diagram 2
15 per cent solution — Diagram 3

The differences shown in the three drawings are due to properties of the cell and its surrounding solution.

Suppose the same experiment is carried out using a salt solution instead of a sugar solution. What will fill the space between the cell wall and the protoplast in Diagram 3?

A water

B air

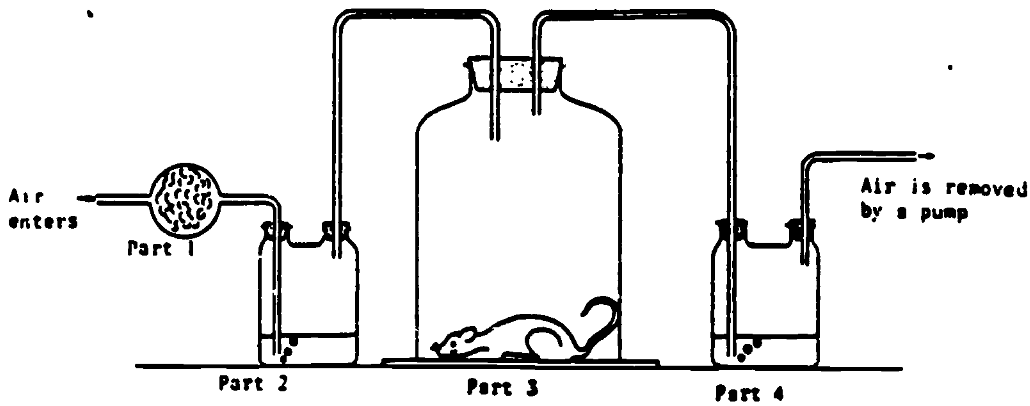
C salt solution

D ectoplasm

E cell sap

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B205)	47.4	47.0	48.9	NA		.03
1986	B1	(B127)	46.5	49.0	43.6	NA		.17

28 This question refers to the following diagram of apparatus used to show that an animal gives out carbon dioxide in respiration.



Part 1 contains a substance which removes carbon dioxide from the air passing through it. Parts 2 and 4 both contain a liquid which changes in appearance when carbon dioxide passes through it.

Of the following kinds of containers for the animal which one would give the quickest result?

A a small container

B a large container

C a container in bright light

D a container covered with a dark cloth

E a container in which the air is kept moist by means of a wet cotton ball

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B226)	68.7	63.8	74.7	NA		.37
1986	B1	(B128)	56.5	53.6	60.3	NA		.38
1983/84	3P	(3M12)	82.0	78.2	84.[illegible]		7.0	.33
1983/84	3N	(3M12)	64.7	63.6	66.0		NA	.42
1970	3P	(10A/25)	74.9	65.4	78.0			
1970	3N	(10A/25)	54.0	51.2	58.2			
1986	2	(2M10)	51.9	48.9	54.8	NA		.36
1983	2	(2M10)	64.7	62.8	66.7		22.0	.42
1970	2	(4A/31)	56.4	52.5	61.1	43.3		

29 The following item refers to the drawings and the descriptive paragraph below.

X and Y represent two forms of the same moth, a light speckled form and a predominantly dark, or melanic, form.

X Y

During the 19th century the air in some parts of England became increasingly polluted with soot through the growth of industry based on the burning of coal. One effect of this pollution was that lichens would no longer grow on the trunks and branches of trees as these became blackened with soot.

Until 1850 the only form of this moth that had been recorded was the light form X. Then in 1850 the dark form Y was reported from one of these industrial areas. By the end of the 19th century the dark form had become quite common and now it is, in many locations, the commoner of the two forms, especially in the vicinity of large towns, where it often comprises as much as 95% of the total population, although the light form predominates in areas away from large centers of population.

Which of the following best explains the appearance of the dark specimen in 1850?

A The color change was induced by air pollution.

B The organisms adapted themselves to the change in external environment.

C Air pollution affected the moths directly after their emergence from the pupal stage.

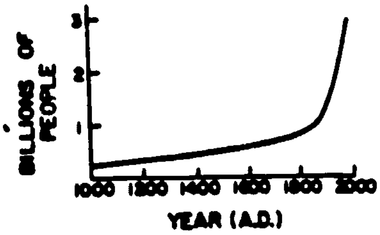
D A mutation, that had occurred before but had failed to become established, became established because it was favored by changes in the external environment.

E The caterpillars ate soot contaminated leaves and dark moths developed from them.

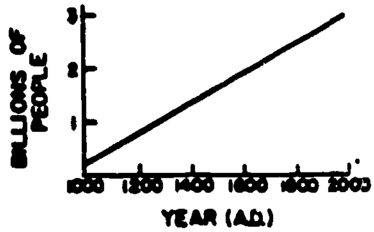
Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B223)	34.4	32.9	36.3	NA		29
1986	B1	(B129)	28.0	30.2	25.6	NA		.16

30 Which graph best shows the human population growth in the world during the past 1,000 years?

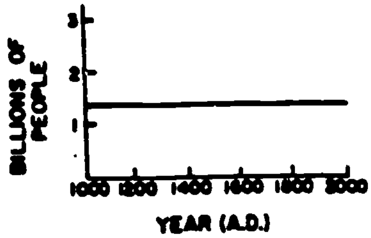
A



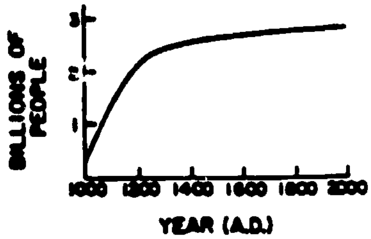
B



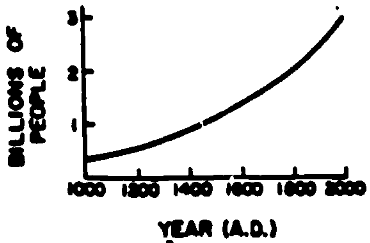
C



D



E



A Graph A

B Graph B

C Graph C

D Graph D

E Graph E

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B1	(B130)	18.0	11.2	25.9	NA		.18
1986	B2	(B230)	25.2	19.0	34.2	NA		.28
1983/84	3P	(3H34)	44.0	29.9	52.4		11.0	.38
1983/84	3N	(3H34)	24.3	18.6	31.4		NA	.35
1983	2	(2A15)	16.3	13.2	20.2		28.0	.25
1983	1	(1A12)	10.0	8.8	10.8		36.0	-.01

APPENDIX B:

BIOLOGY CONTENT TEST II

THIRTY BIOLOGY TEST ITEMS PRESENTED TO SECOND-YEAR (ADVANCED) BIOLOGY STUDENTS

NOTE: Item analysis data are presented in a chart following each item as explained in the following sample diagram.

Year of testing when the same item was used for comparison among groups.

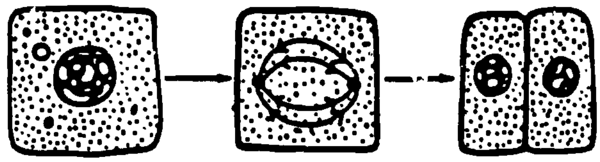
Age group tested: B1 = 1st year biology, B2 = 2nd year biology, 1 = 10-yr. olds or that grade wherein they were enrolled, and 2 = 14-yr olds or equivalent grade (see P.49)

Test item number and % of respondents who answered correctly in U.S. and Intl. samples (see pp. 61-62).

(OTL = Teacher rating of students' opportunity to learn test item content.)

		% Correct						
Year	Pop	Item #	All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis. (Rel. measure)
1986	B1	(B107)	66.2	65.0	66.9	NA	20.0	.19
1983	2	(2M03)	62.7	59.5	65.5	NA		.19
1970	1	(1B/7)	47.2	45.4	49.3	45.1		.24

1 The following diagrams represent a cell process.



If the cell in Diagram 1 contains four chromosomes, how many chromosomes would be present in each cell in Diagram 3?

A 1
B 2
C 4
D 8
E 16

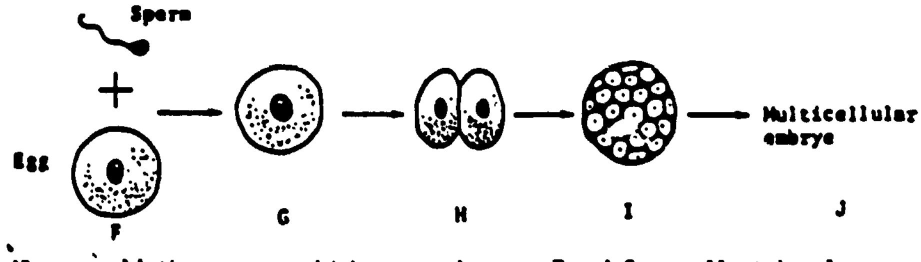
Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B201)	42.1	36.0	49.9	NA		.40
1986	B1	(B117)	29.2	26.5	32.8	NA		.34

2 What initially determines whether a human baby is going to be a male or a female?

A The DNA in the sperm.
B The DNA in the egg.
C The RNA in the sperm.
D The RNA in the egg.
E The DNA and RNA in both sperm and egg.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B202)	48.5	47.6	49.1	NA		.33
1986	B1	(B118)	31.8	31.2	32.4	NA		.33

3



Where would the process which occurs between F and G normally take place in humans?

A uterus

B ovary

C testis

D oviduct

E vagina

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	[illegible]	(B203)	32.1	29.0	36.8	NA		.32
1986	B1	(B121)	20.7	19.0	22.4	NA		.23

4 The diagrams represent three cells with membranes of different permeability. The dots show sugar molecules which cannot pass through the cell membrane.

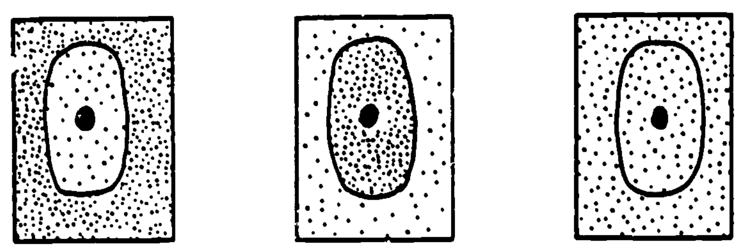


Diagram 1 Diagram 2 Diagram 3

Into which cell(s) will the most water molecules diffuse in from the outside?

A 1 only

B 2 only

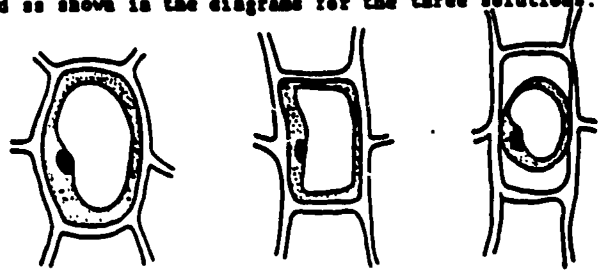
C 1 and 2 only

D 2 and 3 only

E 1, 2, and 3

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B204)	44.2	43.4	44.9	NA		.22
1986	B1	(B122)	37.0	37.3	37.3	NA		.10

5 Similar fragments of a certain plant tissue were placed in 1%, 9%, and 15% sugar solutions respectively. When viewed under the microscope after they had reached equilibrium with the bathing solution, single cells appeared as shown in the diagrams for the three solutions.



1 per cent solution — Diagram 1; 9 per cent solution — Diagram 2; 15 per cent solution — Diagram 3

The differences shown in the three drawings are due to properties of the cell and its surrounding solution.

Suppose the same experiment is carried out using a salt solution instead of a sugar solution. What will fill the space between the cell wall and the protoplast in diagram 3?

A water

B air

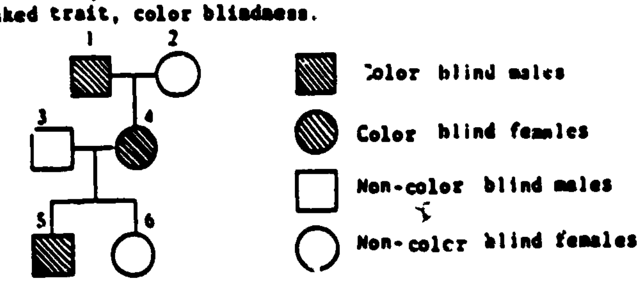
C salt solution

D ectoplasm

E cell sap

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B205)	47.4	47.0	48.9	NA		.03
1986	B1	(B127)	46.5	49.0	43.6	NA		.17

6 The next question is based on the following human pedigree of a sex-linked trait, color blindness.



What person(s) could have no genes for color blindness?

A 2 only

B 3 only

C 2 and 3

D 3 and 6

E 6 only

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B206)	26.9	27.9	26.2	NA		.24

7 Two alternative color characteristics in mice are "hooded" and "white" When homozygous parents of both colors are crossed all the offspring are hooded. If these F_1 hooded rats are mated together and produce litters totalling 50 rats, which of the following proportions is most likely?

- A 50 hooded : none white
- B 50 white : none hooded
- C 38 white : 12 hooded
- D 24 white : 26 hooded
- E 10 white : 40 hooded

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B207)	31.2	30.3	30.7	NA		.30
1986	B1	(B123)	22.4	22.5	22.3	NA		.25

8 In a population of 1000 fruit flies, the percentages of gene pairs were:

TT = 15 per cent   Tt = 51 per cent   tt = 34 per cent.

If the fruit flies were free to breed normally, and if nothing happened to disturb the "gene pool", what would be the approximate percentage of tt two generations later?

- A 15 per cent
- B 34 per cent
- C 51 per cent
- D 68 per cent
- E 75 per cent

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B208)	38.7	39.0	37.2	NA		.35
1986	B1	(B124)	34.7	35.2	34.4	NA		.18

9 In many breeds of cattle the polled condition (absence of horns) is dominant over the presence of horns, and homozygous red crossed with homozygous white produces roan (intermingled red and white hairs) color. Which of the following crosses will produce only horned roan offspring?

- A polled red x horned white
- B horned roan x horned roan
- C horned red x horned white
- D polled roan x horned roan
- E polled white x horned roan

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B209)	43.2	41.6	45.7	NA		.29
1986	B1	(B125)	37.1	37.3	37.8	NA		.18

10 Which of these substances is found in every living cell?

A protein

B chlorophyll

C cellulose

D starch

E hemoglobin

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B210)	59.7	55.4	65.8	NA		.28
1986	B1	(B113)	48.6	45.7	51.4	NA		.17

11 How does lymph enter the tissues of humans?

A by blood pressure

B by the action of the liver

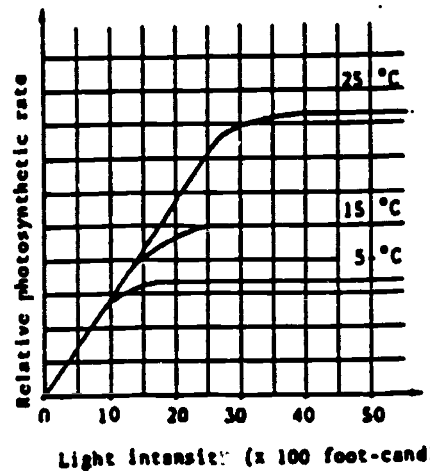
C by the action of the intestinal villi

D by the action of the kidney

E by a diffusion gradient

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B211)	18.3	16.3	20.[illegible]	NA		.08

12 In an experiment with a certain plant, the photosynthetic rate per unit of a leaf area was measured at different light intensities. The experiment was repeated at three different temperatures, 5°C, 15°C, and 25°C. An adequate supply of carbon dioxide was maintained throughout the experiments. The graph shows the results.



On the basis of the data given in the graph, which factor or factors determine the photosynthetic rate in light intensities more than 3,000 foot-candles?

- A light intensity
- B temperature
- C temperature and light intensity
- D water status of plant
- E no factor can be ascertained from the graph.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B212)	32.7	26.1	40.8	NA		.33

13 What happens first when chlorophyll absorbs light in a living plant cell?

A Carbon dioxide is fixed into phosphoglyceric acid.

B Carbohydrates are formed.

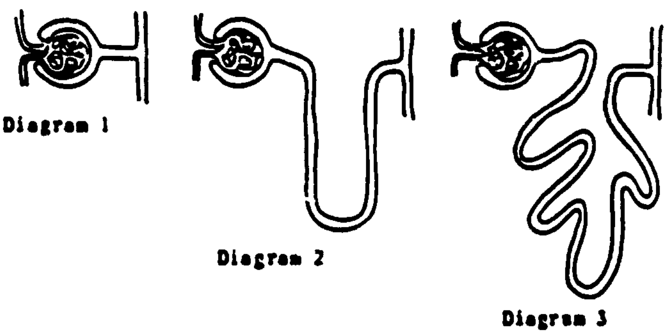
C Adenosine triphosphate (ATP) is converted into adenosine diphosphate (ADP).

D Adenosine diphosphate (ADP) is converted into adenosine triphosphate (ATP) and hydrogen is released from water.

E Oxygen is released from carbon dioxide.

			% Correct				OTL (%)	Pt.
Year	Pop	Item #	All	Female	Male	Int'l	Ratings	Bis.
1986	B2	(B213)	27.5	26.0	28.9	NA		.20

14 The primary function of a kidney tubule is to reabsorb water. The diagrams show three types of kidney tubules (nephrons).



Which kidney tubule (nephron) is most likely to occur in a desert animal?

A 1

B 2

C 3

D It will depend on whether the animal is cold blooded or warm blooded.

E It will depend on whether the animal is a herbivore or a carnivore.

			% Correct				OTL (%)	Pt.
Year	Pop	Item #	All	Female	Male	Int'l	Ratings	Bis.
1986	B2	(B214)	52.8	51.0	55.9	NA		.22

15 Tissue from a cow is shown on analysis to contain protein, a small amount of fat, some iron, and large quantities of vitamins A and D. Which part of the body did it come from?

A muscles

B kidney

C liver

D heart

E brain

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B215)	36.7	36.6	35.7	NA		.10

16 In slightly diluted sea water, the small marine worm Gunda swells when deprived of oxygen and shrinks again when oxygen is supplied. What is the most likely explanation?

A Lack of oxygen results in an incomplete oxidation of waste products.

B The lack of oxygen increases water absorption.

C Excess water is poisonous to the organism.

D When less oxygen is available, there is not enough energy to oppose entry of water by means of osmosis.

E An increase of surface area gives a better means of oxygen absorption.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B216)	27.5	28.7	24.6	NA		-.07

17 Which one of the following processes in plants is not controlled by hormones?

A water uplift in the stem

B downward growth of the radicle

C flowering under the influence of increasing day length

D falling of the leaves of deciduous trees in autumn

E orientation of shoots towards lateral light

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B217)	37.2	33.4	41.6	NA		.40
1986	B1	(B114)	29.3	27.2	31.7			.25

18 Secretions of endocrine organs in animals are not directly responsible for which one of the following?

- A calcium metabolism
- B secretion by the adrenal cortex
- C changes in the uterine lining
- D changes of body temperature
- E general body growth

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B218)	27.4	25.9	29.2	NA		28

19 Cobalt chloride paper is blue when dry. It gradually changes color to pink in the presence of water vapor. Three 1 cm^2 dry cobalt chloride papers were treated as follows:

The first was fastened to the upper surface of a leaf by means of a clip, the second to the lower surface in a similar way, and the third hung free in the air. The time taken for the papers to achieve a standard pink color was noted. The first took 9 minutes, the second 12 minutes, the third 18 minutes.

Which of the following conclusions is justified on this evidence alone?

- A There are more stomata on the lower surface of the leaf than on the upper.
- B No water vapor is given off from the lower surface of the leaf.
- C The upper leaf surface gives off more water vapor than the lower.
- D Both leaf surfaces give off water vapor at the same rate.
- E There are no stomata on the upper surface of the leaf.

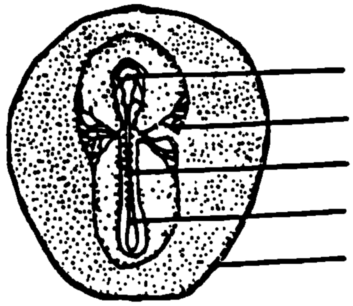
Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B219)	70.5	70.0	72.3	NA		.23

20 In order to obtain two crops in one growing season a farmer planted some seeds which he had harvested the previous week but the seeds failed to germinate. What can be concluded from this observation?

- A The farmer did not provide the right conditions for germination.
- B The seeds needed a longer period of maturation.
- C The farmer had not removed inhibiting substances.
- D The seeds required a period of low temperature.
- E The data are inadequate for a conclusion to be reached.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B220)	52.6	53.8	51.1	NA		.19

21 The diagram shows a 33-hour chick embryo. Which structure brings food to the growing embryo?



Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B221)	57.7	55.4	61.5	NA		.31
1986	B1	(B126)	46.9	45.7	48.3	NA		.25

22 The following results are from experiments which were made to find how long it took for newborn babies of different mammals to double in weight.

Mammal	Time in days to double the weight of the newborn baby	Percentage protein in the milk of the mother
human	180	1.6
horse	60	2.0
cow	47	3.5
pig	18	5.9
sheep	10	6.5
dog	8	7.1
rabbit	6	10.4

What do the results of these experiments suggest?

A The larger the mammal, the greater the protein concentration in the milk.

B The smaller the mammal, the greater the protein concentration in the milk.

C The greater the protein concentration in the mammal's milk the slower the newborn baby will double its weight.

D The greater the protein concentration in the mammal's milk the faster the newborn baby will double its weight.

E There appears to be no relationship between protein concentration in mammal's milk and time taken for a newborn baby to double its birth weight.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B222)	69.1	65.9	72.8	NA		.39
1986	B1	(B110)	49.5	49.5	49.3	NA		.38
1983/84	3P	(3M22)	78.7	76.6	79.7		11.0	.41
1983/84	3N	(3M22)	54.4	54.0	54.8		NA	.46
1983	2	(2A08)	50.7	50.1	51.2		30.0	.45

23 The following item refers to the drawings and the descriptive paragraph below.

X and Y represent two forms of the same moth, a light speckled form and a predominantly dark, or melanic, form.

X Y

During the 19th century the air in some parts of England became increasingly polluted with soot through the growth of industry based on the burning of coal. One effect of this pollution was that lichens would no longer grow on the trunks and branches of trees as these became blackened with soot.

Until 1850 the only form of this moth that had been recorded was the light form X. Then in 1850 the dark form Y was reported from one of these industrial areas. By the end of the 19th century the dark form had become quite common and now it is, in many localities, the commoner of the two forms, especially in the vicinity of large towns, where it often comprises as much as 95% of the total population, although the light form predominates in areas away from large centers of population.

Which of the following best explains the appearance of the dark specimen in 1850?

A The color change was induced by air pollution.

B The organisms adapted themselves to the change in external environment.

C Air pollution affected the moths directly after their emergence from the pupal stage.

D A mutation, that had occurred before but had failed to become established, became established because it was favored by changes in the external environment.

E The caterpillars ate soot contaminated leaves and dark moths developed from them.

Year	Pop	Item #	% Correct				OTL (%)	Pt.
			All	Female	Male	Int'l	Ratings	Bis.
1986	B2	(B223)	34.4	32.9	36.3	NA		.29
1986	B1	(B129)	28.0	30.2	25.6	NA		.38

24 All of the following are aspects of the reproductive process. Which one of them must occur before we can be certain that fertilization has taken place?

A A male organism must find a mate.

B Reproductive organs must be produced.

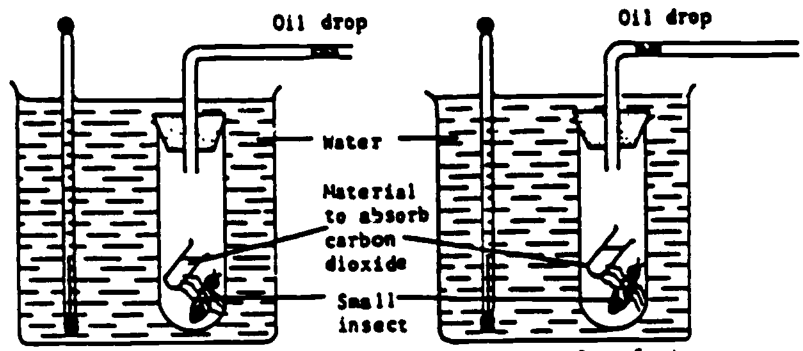
C The nucleus of a male gamete must fuse with that of a female gamete.

D A spermatozoon must reach an egg cell.

E A female gamete must provide a store of food for the embryo.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B224)	58.2	53.7	62.8	NA		.34
1986	B1	(B111)	40.3	37.6	43.6	NA		.34
1983/84	3P	(3M09)	58.9	55.5	61.2		5.0	.39
1983/84	3N	(3M09)	38.9	38.4	39.4		NA	.37
1970	3P	(10A/7)	52.9	55.4	52.1			
1970	3N	(10A/7)	34.6	33.8	35.9			

25 Animals take in oxygen and give out carbon dioxide. Ordinary air contains very little carbon dioxide.



Apparatus as first set up   Apparatus after 5 minutes

Which of the following can be measured with the above apparatus?

A The rate of movement of the animal.

B The amount of heat produced by the animal.

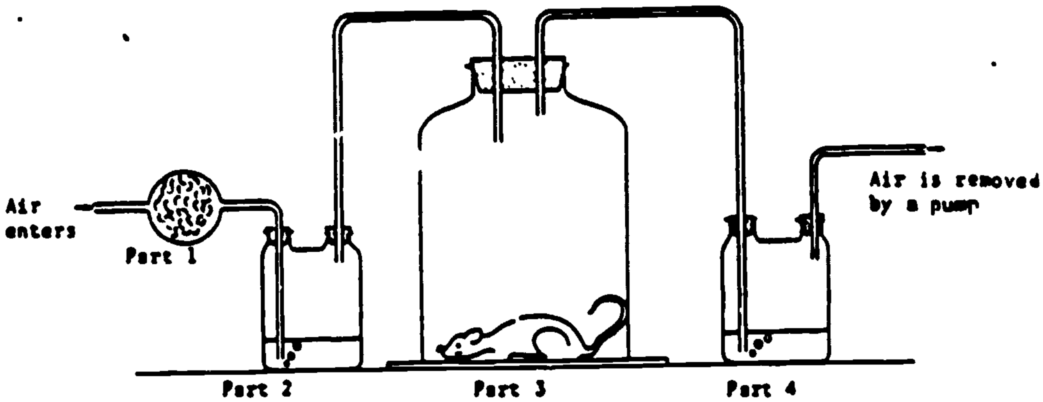
C The rate of respiration of the animal.

D The effect of carbon dioxide on the animal.

E The amount of carbon dioxide absorbed by the animal.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B225)	45.2	39.5	53.2	NA		.33
1986	B1	(B120)	32.8	27.0	40.1	NA		.28
1983/84	3P	(3M10)	57.5	49.2	62.7		5.0	.37
1983/84	3N	(3M10)	37.1	31.8	44.2		NA	.39
1970	3P	(10A/27)	52.4	42.8	55.5			
1970	3N	(10/A27)	33.7	27.0	43.2			
1986	2	(2M12)	31.2	26.3	35.7	NA		.15
1983	2	(2M12)	35.3	29.4	41.6		21.0	.27
1970	2	(4B/31)	35.1	30.5	40.5	37.2		

26 This question refers to the following diagram of apparatus used to show that an animal gives out carbon dioxide in respiration.



Part 1 contains a substance which removes carbon dioxide from the air passing through it. Parts 2 and 4 both contain a liquid which changes in appearance when carbon dioxide passes through it.

Of the following kinds of containers for the animal which one would give the quickest result?

A a small container

B a large container

C a container in bright light

D a container covered with a dark cloth

E a container in which the air is kept moist by means of a wet cotton ball

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B226)	68.7	63.8	74.7	NA	87.9	.37
1986	B1	(B128)	56.5	53.6	60.3	NA	69.3	.38
1983/84	3P	(3M12)	82.0	78.2	84.1		7.0	.33
1983/84	3N	(3M12)	64.7	63.6	66.0		NA	.42
1970	3P	(10A/25)	74.9	65.4	78.0			
1970	3N	(10A/25)	54.0	51.2	58.2			
1986	2	(2M10)	51.9	48.9	54.8	NA	40.8	.36
1983	2	(2M10)	64.7	62.8	66.7		22.0	.42
1970	2	(4A/31)	56.4	52.5	61.1	43.3		

27 How does natural selection operate in a population?

A The members are all alike.

B The members are equally able to survive any environmental change.

C The members differ so only some survive when the environment changes.

D The members do not adapt to environmental changes.

E The members of the entire population adapt to environmental changes.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B227)	60.4	60.2	61.7	NA		.44
1986	B1	(B116)	51.7	54.7	49.4	NA		.36

28 It has been noticed in recent years that the proportion of insects surviving after exposure to certain insecticides has shown a gradual increase with succeeding generations. Of the following, which is the best explanation?

A World changes in climate have provided a new environment.

B Offspring of insects which have been exposed to the insecticide have inherited an immunity.

C Elimination of the less resistant strains gives the resistant ones a greater chance of success

D Changes in the habits of the insects have enabled them to survive.

E The insecticide causes favorable mutations.

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B228)	12.3	7.7	17.6	NA		.29

29 The Galapagos Islands in the Pacific are believed never to have been connected to the mainland. In the Islands there are about 14 species of finch-like birds with few obvious relatives except on the South American mainland. The finches vary from island to island. There is a close resemblance between species in plumage, calls, nests, and eggs, but each species differs greatly in beak structure according to the diet. The species do not interbreed and do not compete for food.

It is stated on this evidence that isolation from the South American mainland and different habitats on the Islands are important factors in the production of new species.

A The statement is supported by the information given.

B The statement is not supported by the information given.

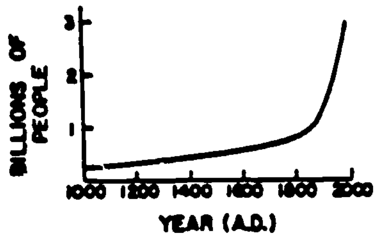
C The statement is contradicted by the information given.

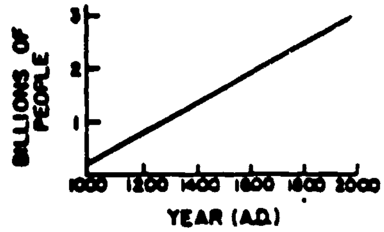
D The statement is known to be false but this is not supported by the information given.

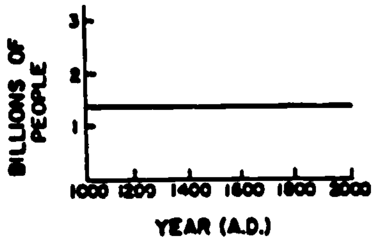
E No relevant information is given.

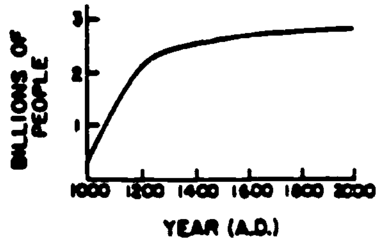
Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B229)	45.9	43.1	50.7	NA		.21
1986	B1	(B119)	44.9	44.6	45.5	NA		.30

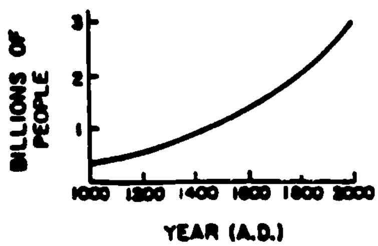
30 Which graph best shows the human population growth in the world during the past 1,000 years?

A


B


C


D


E


A Graph A
B Graph B
C Graph C
D Graph D
E Graph E

Year	Pop	Item #	% Correct All	Female	Male	Int'l	OTL (%) Ratings	Pt. Bis.
1986	B2	(B230)	25.2	19.0	34.2	NA		.28
1986	B1	(B130)	18.0	11.2	25.9	NA		.18
1983/84	3P	(3M34)	44.0	29.9	52.4		11.0	.38
1983/84	3N	(3M34)	24.3	18.6	31.4		NA	.35
1983	2	(2A15)	16.3	13.2	20.2		28.0	.25
1983	1	(1A12)	10.0	8.8	10.8		36.0	-.01

APPENDIX C:

QUESTIONNAIRE ITEMS AND RESPONSES FIRST YEAR BIOLOGY POPULATION

THE ITEMS HAVE BEEN ABBREVIATED AND PRESENTED IN TABULAR FORM

APPENDIX C: RESPONSES TO STUDENT QUESTIONNAIRE BIOLOGY I REPORTED AS PERCENTILES

1. What is your sex?

A	male	44.0
B	female	51.8

2. Further education after high school?:

A	not decided	18.4
B	none further	3.4
C	1 - 2 years	10.9
D	3 - 4 years	35.8
E	more than 4 years	27.2

3. Kinds of courses to be taken in further education:

A	not decided	14.8
B	none further	2.4
C	science/ applied sci.	24.3
D	social science	10.7
E	business/commercial	13.8
F	education/teaching	3.1
G	art	7.4
H	agriculture	2.3
I	English/language	4.1
J	other	11.9

4. Televison viewing time

A	never during week	3.2
B	less than 1 hr/ week	8.4
C	about 1 hour	11.1
D	about 2 hours	17.7
E	about 3 hours	17.8
F	about 4 hours	12.4
G	about 5 hours	9.7
H	6 hours . r more	14.9

5. Hours spent per week on homework for all subjects

A	none assigned	1.2
B	do not do it	6.8
C	up to 2 hours	28.5
D	2 to 5 hours	26.5
E	5 to 10 hours	20.4
F	10 to 20 hours	11.0
G	over 20 hours	2.1

6. Hours spent out of class on science homework

A	none assigned	8.3
B	do not do it	7.5
C	up to 2 hours	55.0
D	2 to 5 hours	20.2
E	5 to 10 hours	3.5
F	over 10 hours	1.1

7. Best description of grades so far in school:

A	mostly A	13.4
B	about half A and B	18.2
C	mostly B	18.4
D	about half B and C	23.5
E	mostly C	12.1
F	about half C and D	8.0
G	mostly D	1.1
H	mostly below D	0.6

8. Electronic calculator available for use at home after school:

A	yes	51.7
B	no	43.6

9. Computers at your school:

A	yes	93.3
B	no	2.3

10. Time spent each week using computer:

A	never used at school	66.1
B	up to two hours	17.3
C	2 to 5 hours	7.6
D	5 to 10 hours	3.2
E	more than 10 hours	1.4

11. Years of mathematics after tenth grade:

A	none	0.8
B	one	20.9
C	two	62.0
D	three	8.8
E	four	1.7
F	more than four	1.5

APPENDIX C: RESPONSES TO STUDENT QUESTIONNAIRE BIOLOGY I REPORTED AS PERCENTILES

12. Highest level of school your father (equivalent) completed:

A	not living with father	4.9
B	Grade School	2.3
C	some High School	6.7
D	High School	21.1
E	Technical/ vocational	17.5
F	College or higher	35.4
G	I don't know	7.4

13. Best description of father's (or equiv.) work:

A	not living with father	8.3
B	semi-skilled	12.0
C	skilled	22.9
D	clerical/sales	10.5
E	professional/ exec.	29.9
F	homemaker	1.0
G	some other	10.1

14. Highest level of school of mother or equivalent:

A	not with mother	0.3
B	Grade School	2.3
C	some High School	6.5
D	High School	31.4
E	technical/ vocational	19.3
F	College or higher	30.4
G	don't know	5.3

15. Best description of mother's (or equivalent) work:

A	not with mother	1.1
B	semi-skilled	13.8
C	skilled	9.8
D	clerical/sales	23.3
E	professional/ exec.	19.1
F	homemaker	20.8
G	some other	6.9

16. Number of books in home:

A	none or few (1-10)	2.5
B	few (11-25)	9.9
C	1 bookcase (26-100)	21.9
D	2 bkcases (101-250)	24.7
E	3-4 cases (251-300)	25.3
F	one room (over 500)	11.3

APPENDIX D:

QUESTIONNAIRE ITEMS AND RESPONSES ADVANCED BIOLOGY POPULATION

THE ITEMS HAVE BEEN ABBREVIATED AND PRESENTED IN TABULAR FORM

APPENDIX D: RESPONSES TO STUDENT QUESTIONNAIRE BIOLOGY II REPORTED AS PERCENTILES

1. What is your sex?

A	male	40.3
B	female	55.4

2. Further education after high school?:

A	not decided	9.0
B	none further	2.3
C	1 - 2 years	5.8
D	3 - 4 years	34.4
E.	more than 4 years	44.3

3. Kinds of courses to be taken in further education:

A	not decided	9.0
B	none further	2.6
C	science/ applied sci.	40.1
D	social science	9.3
E	business/commercial	13.7
F	education/teaching	3.5
G	art	3.8
H	agriculture	2.3
I	English/language	3.8
J	other	6.3

4. Televison viewing time:

A	never during week	4.0
B	less than 1 hr/ week	11.2
C	about 1 hour	13.3
D	about 2 hours	20.0
E	about 3 hours	19.5
F	about 4 hours	12.3
G	about 5 hours	5.9
H	6 hours or more	9.5

5. Hours spent per week on homework for all subjects:

A	none assigned	0.9
B	do not do it	5.6
C	up to 2 hours	27.3
D	2 to 5 hours	19.2
E	5 to 10 hours	5.9
F	10 to 20 hours	5.9
G	over 20 hours	1.2

6. Hours spent out of class on science homework:

A	none assigned	7.6
B	do not do it	8.4
C	up to 2 hours	54.0
D	2 to 5 hours	19.2
E	5 to 10 hours	5.9
F	over 10 hours	0.5

7. Best description of grades so far in school:

A	mostly A	18.1
B	about half A and B	23.6
C	mostly B	21.6
D	about half B and C	19.5
E	mostly C	8.5
F	about half C and D	3.7
G	mostly D	0.8
H	mostly below D	0.0

8. Electronic calculator available for use at home after school:

A	yes	67.0
B	no	28.6

9. Computers at your school:

A	yes	94.0
B	no	1.4

10. Time spent each week using computer:

A	never used at school	59.2
B	up to two hours	16.4
C	2 to 5 hours	14.4
D	5 to 10 hours	4.4
E	more than 10 hours	1.3

11. Years of mathematics after tenth grade:

A	none	0.0
B	one	1.0
C	two	23.2
D	three	38.0
E	four	25.8
F	more than four	7.8

APPENDIX D: RESPONSES TO STUDENT QUESTIONNAIRE BIOLOGY II
REPORTED AS PERCENTILES

12. Highest level of school your father (equivalent) completed:

A	not living with father	2.7
B	Grade School	2.1
C	some High School	5.6
D	High School	21.3
E	technical/ vocational	14.8
F	College or higher	45.7
G	I don't know	3.0

13. Best description of father's (or equiv.) work:

A	Not living with father	4.3
B	semi-skilled	13.7
C	skilled	19.9
D	clerical/sales	7.9
E	professional/ Exec.	41.3
F	homemaker	0.0
G	some other	7.6

14. Highest level of school of mother or equivalent:

A	not with mother	0.5
B	Grade School	1.0
C	some High School	7.3
D	High School	29.2
E	technical/ vocational	19.2
F	College or higher	35.5
G	don't know	2.8

15. Best description of mother's (or equivalent) work:

A	not with mother	1.3
B	semi-skilled	13.4
C	skilled	7.0
D	clerical/sales	21.5
E	professional/ Exec.	24.4
F	homemaker	23.0
G	some other	4.9

16. Number of books in home:

A	none or few (1-10)	1.3
B	few (11-25)	4.4
C	1 bookcase (26-100)	22.2
D	2 bkcases (101-250)	28.0
E	3-4 cases (251-300)	25.7
F	one room (over 500)	14.0

APPENDIX E:

MATHEMATICS TEST: FIRST YEAR BIOLOGY POPULATION

FIFTEEN MATHEMATICS TEST ITEMS PRESENTED TO BIOLOGY POPULATION I

1 0.00046 is equal to

A 4.6×10^{-5}

B 4.6×10^{-4}

C 46×10^{-4}

D 46×10^{-3}

E 0.46×10^{3}

2 The value of $2^3 \times 3^2$ is

A 30

B 36

C 64

D 72

E none of these

3 Four times a certain number is 24 more than the number. What is the number?

A 5

B 6

C 8

D 12

E 18

4 What is the square root of 12 x 75?

A 6.25

B 30

C 87

D 625

E 900

5 There are 227 students in a school. Every student in the school belongs to either the music club or the sports club, and some students belong to both clubs. The music club has 120 members, and 36 of these are also members of the sports club. What is the total membership of the sports club?

A 84

B 107

C 120

D 143

E 191

6 $\frac{a}{15} - \frac{b}{5}$ is equal to

A $\frac{a - 3b}{15}$

B $\frac{5a - 15b}{15}$

C $\frac{a - b}{10}$

D $\frac{a - b}{75}$

E $\frac{3a - 5b}{75}$

7 A rectangle is twice as long as it is wide. If it has an area of 32 cm^2, what is its <u>perimeter</u>?

A 4 cm

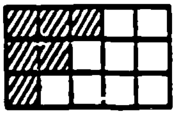
B 12 cm

C 16 cm

D 20 cm

E 24 cm

8



In the figure the little squares are all the same size, and the area of the whole rectangle is equal to 1.

The area of the shaded part is equal to

A $\frac{2}{15}$

B $\frac{1}{3}$

C $\frac{2}{5}$

D $\frac{3}{8}$

E $\frac{1}{2}$

9 Frank decided to make a bar graph to show the maximum temperature on four days. He made this table to help him draw the graph.

Day	Mon	Tue	Wed	Thur
Maximum temperature	16 °C	18 °C	21 °C	24 °C
Height of bar	8 cm	9 cm		12 cm

What should be the height of the bar for Wednesday?

A 9.5 cm

B 10 cm

C 10.5 cm

D 21 cm

E 42 cm

10 If $\frac{2}{\Delta} = \frac{\Delta}{8}$, then Δ can be equal to

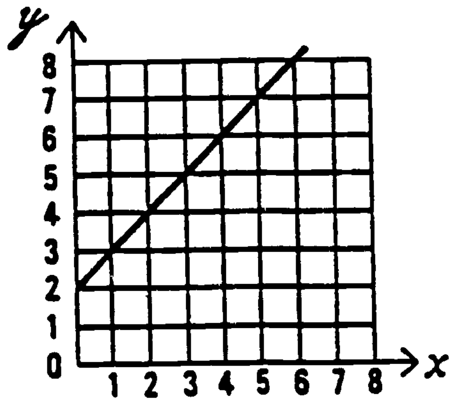
A 1

B 2

C 4

D 8

E 16



11 The equation of the graph shown above is

A $y = x + 1$

B $y = x + 2$

C $y = 2x + 1$

D $y = 2x + 2$

E $y = 3x - 2$

12 A solid plastic cube with edges 1 centimeter long weighs 1 gram. How much will a solid cube of the same plastic weigh if each edge is 2 centimeters long?

A 16 grams

B 8 grams

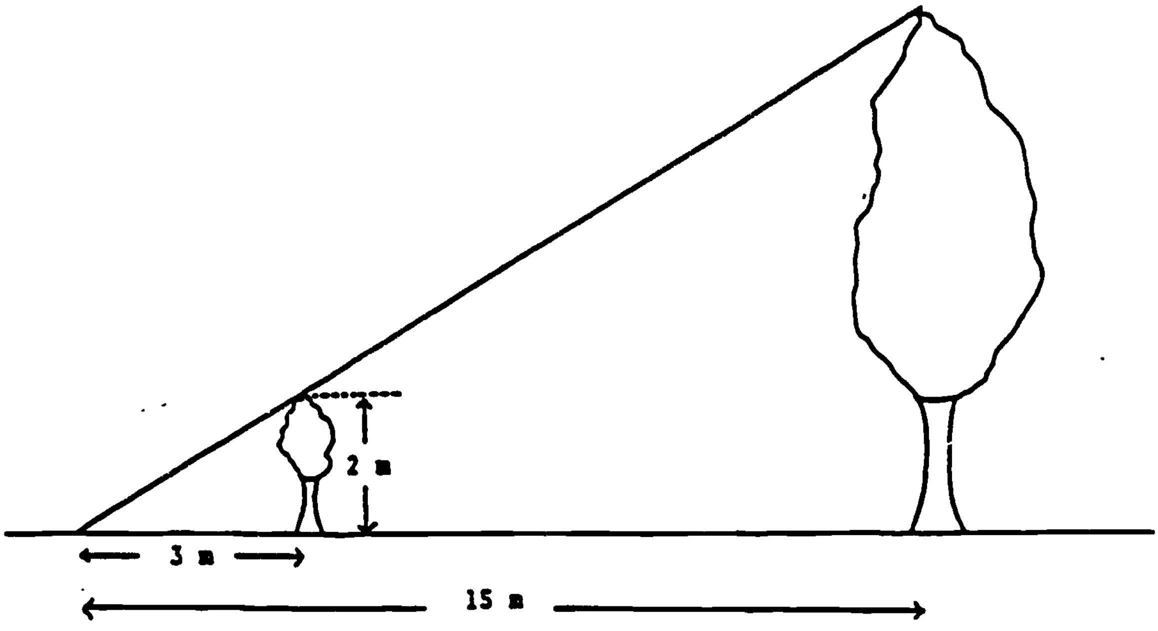
C 4 grams

D 3 grams

E 2 grams

13 A factory produces m cars per week. How many cars per week will it produce after production is increased p per cent?

- A $100p + m$
- B $100m + mp$
- C $\frac{m + mp}{100}$
- D $m + \frac{mp}{100}$
- E $\frac{p}{100} + m$



14 The picture above shows a method of finding the height of a tall tree using a short tree. What is the height of the tall tree?

- A 8 meters
- B 10 meters
- C 15 meters
- D 18 meters
- E 20 meters

15 The expression $6 \times 10^5 + 2 \times 10^4 + 7 \times 10^3 + 9$ is equal to

- A 6,279
- B 62,709
- C 602,709
- D 627,009
- E 6,020,709

STOP. DO NOT CONTINUE UNTIL YOU ARE TOLD TO DO SO.

APPENDIX F:

MATHEMATICS TEST: ADVANCED BIOLOGY POPULATION

FIFTEEN MATHEMATICS TEST ITEMS PRESENTED TO BIOLOGY POPULATION II

1 There are 227 students in a school. Every student in the school belongs to either the music club or the sports club, and some students belong to both clubs. The music club has 120 members, and 36 of these are also members of the sports club. What is the total membership of the sports club?

A 84

B 107

C 120

D 143

E 191

2 The expression $6 \times 10^5 + 2 \times 10^4 + 7 \times 10^2 + 9$ is equal to

A 6,279

B 62,709

C 602,709

D 627,009

E 6,020,709

3 $\frac{a}{15} - \frac{b}{5}$ is equal to

A $\frac{a - 3b}{15}$

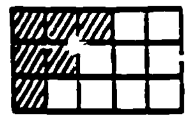
B $\frac{5a - 15b}{15}$

C $\frac{a - b}{10}$

D $\frac{a - b}{75}$

E $\frac{3a - 5b}{75}$

4



In the figure the little squares are all the same size, and the area of the whole rectangle is equal to 1.

The area of the shaded part is equal to

A $\frac{2}{15}$

B $\frac{1}{3}$

C $\frac{2}{5}$

D $\frac{3}{8}$

E $\frac{1}{2}$

5 Frank decided to make a bar graph to show the maximum temperature on four days. He made this table to help him draw the graph.

Day	Mon	Tue	Wed	Thur
Maximum temperature	16 °C	18 °C	21 °C	24 °C
Height of bar	8 cm	9 cm		12 cm

What should be the height of the bar for Wednesday?

A 9.5 cm

B 10 cm

C 10.5 cm

D 21 cm

E 42 cm

6 If $\frac{2}{\Delta} = \frac{\Delta}{8}$, then Δ can be equal to

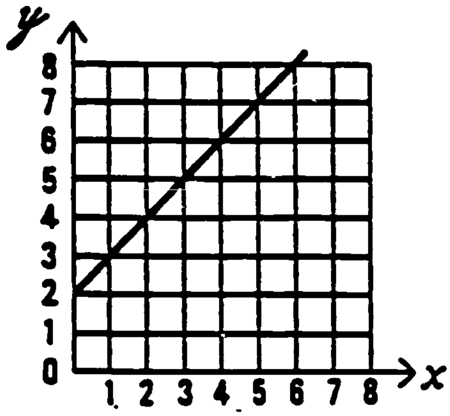
A 1

B 2

C 4

D 8

E 16



7 The equation of the graph shown above is

A $y = x + 1$

B $y = x + 2$

C $y = 2x + 1$

D $y = 2x + 2$

E $y = 3x - 2$

8 A solid plastic cube with edges 1 centimeter long weighs 1 gram. How much will a solid cube of the same plastic weigh if each edge is 2 centimeters long?

A 16 grams

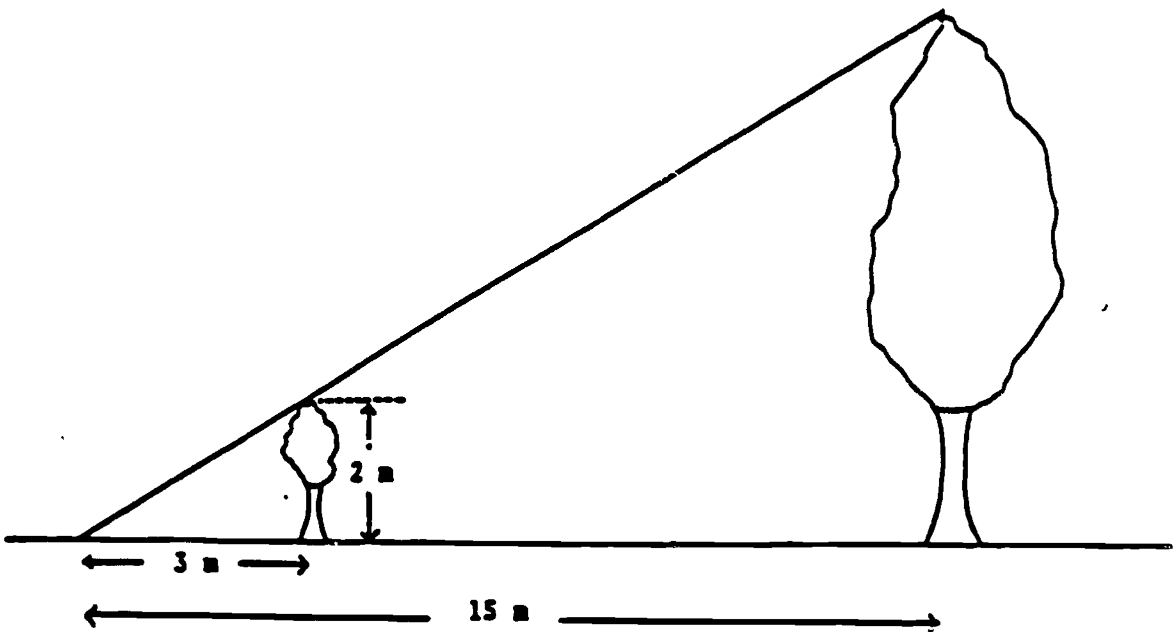
B 8 grams

C 4 grams

D 3 grams

E 2 grams

9



The picture above shows a method of finding the height of a tall tree using a short tree. What is the height of the tall tree?

- A 8 meters
- B 10 meters
- C 15 meters
- D 18 meters
- E 20 meters

10 If $\frac{x}{2} < 7$, then

- A $x < \frac{7}{2}$
- B $x < 5$
- C $x < 14$
- D $x > 5$
- E $x > 14$

11 A factory produces m cars per week. How many cars per week will it produce after production is increased p per cent?

A $100p + m$

B $100m + mp$

C $\frac{m + mp}{100}$

D $m + \frac{mp}{100}$

E $\frac{p}{100} + m$

12 If $xy = 1$ and x is greater than 0, which of the following statements is true?

A When x is greater than 1, y is negative.

B When x is greater than 1, y is greater than 1.

C When x is less than 1, y is less than 1.

D As x increases, y increases.

E As x increases, y decreases.

13 A certain operation written as ∇ is defined by:

$a \nabla b = \frac{b - a}{a}$ for any numbers a and b.

If $5 \nabla b = \frac{2}{5}$, what is the value of b?

A 2

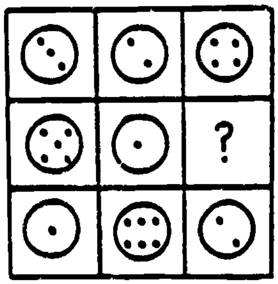
B 3

C 5

D 7

E 9

14



Part of the pattern above is missing as shown by the question mark. Which figure best completes the pattern?

A 

B 

C 

D 

E 

15 What number should go in the space to complete the following number pattern?

2, 4, ..., 48, 240

A 8

B 12

C 16

D 24

E 32

STOP. DO NOT CONTINUE UNTIL YOU ARE TOLD TO DO SO.